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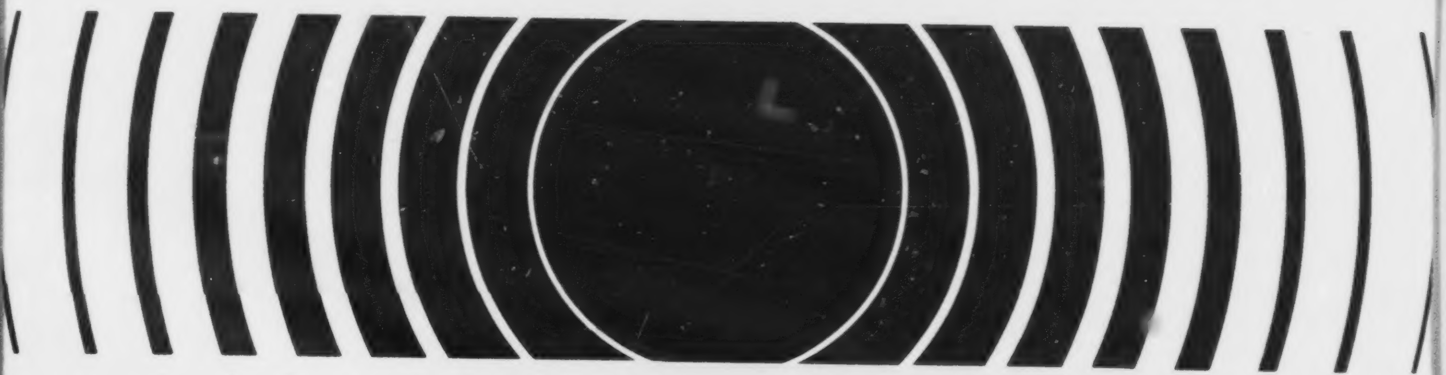

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The report is concerned with the ecological impacts of specific cleanup treatments on the land where they are carried out. The cleanup procedures given apply equally to chemical or radioactive materials. Guidance is provided for cleanup ~~procedures~~ procedures likely to be suggested by government, industry, or environmental groups. The basic types of cleanup procedures for removing or deactiving spilled contamination involve moving people and animals from the affected area, scraping and grading the contaminated soil into windrows, plowing the contamination under, or digging up the contamination and hauling it away. The report describes and evaluates the various land-type cleanup effects in terms of impact of the techniques on the environment. Part I defines seven natural ecosystems and some of their natural derivations. Part II presents managed ecosystems which are imposed on natural ecosystems and are no longer bound by the initial native ecosystem balances. Part III deals with avion and mammilian wild life displaced by cleanup. The appendices discuss the major categories of soil stabilizers; Cleanup treatments and their impacts; and Land types.

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THE ECOLOGICAL IMPACT OF LAND RESTORATION AND CLEANUP

August 1978

U.S. Environmental Protection Agency
Office of Radiation Programs
Criteria and Standards Division
Washington, D.C. 20460

PREFACE

This document contains the results of studies commissioned by the Environmental Protection Agency and carried out by the General Electric Company, Tempo Division, under contract to the Agency. Funding was provided by the Office of Federal Activities under a program to develop information required to improve the quality of Environmental Impact Statements and similar public information materials issued by the Agency.

The material was developed specifically in support of Federal Radiation Protection Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment, prepared by the Office of Radiation Programs. It is intended to directly supplement the guidance and provide information useful for effective planning of remedial actions and for preparation of Environmental Impact Statements where required. Although written primarily from the viewpoint of radiation protection, the scope of the document is sufficiently broad so that it can be expected to have widespread applicability to many other situations where cleanup of residual environmental contamination may be required.

Comments on this document would be appreciated. These should be sent to the Director, Criteria and Standards Division (ANR-460), Office of Radiation Programs.

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DISCLAIMER

This report has been reviewed by the Office of Radiation Programs, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commerical products constitute endorsement or recommendation for use.

ABSTRACT

The basic types of cleanup procedures for removing or deactivating spilled contamination involve moving people and animals from the affected area, scraping or grading the contaminated soil into windrows, plowing the contamination under, or digging up the contamination and hauling it away. This report describes and evaluates these various land-type cleanup effects in terms of impact of the technique on the environment. The cleanup procedures are listed in the following table with brief definitions of proposed cleanup actions. Conclusions about the effects of cleanup on the soil, vegetation, and animals in an area are summarized in the composite effects shown in the following table as a composite ranking for all the areas studied. The rankings are numbered from 0 through 5 for each cleanup treatment. Interpretations of these rankings are as follows:

0 - No measurable change is produced in the ecosystem.

1 - The preferred cleanup because adverse environmental effects upon recovery and side effects of treatment are minimal.

2 - A conditionally acceptable treatment because of significant impact by the treatment and/or the equipment upon the area.

3 - Acceptable as a "last resort" cleanup to remove exceptionally hazardous material while incurring maximum acceptable impact.

4 - Causes unacceptable damage but can be used as an interim cleanup if the injury is erased during the final treatment.

5 - Not applicable to the land type for which it is proposed.

The rankings considered the environmental insult generated during the cleanup, the physical possibility of restoring the area to its original productive state, side effects caused by the equipment needed to perform the cleanup, the impact upon the environment adjacent to the cleaned up area, and the social acceptance of the cleanup work. Not all treatments were expected to be evaluated with all land types; these exceptions are indicated in the table as being outside the scope of this effort.

The primary criterion for the evaluation of cleanup effects was the suitability of the denuded surface as a medium for plant growth. Establishment of a vegetative cover before serious wind and water erosion despoiled the site was considered first and, if revegetation was probable, the time to recover the initial pre-cleanup productivity was considered next. This is the context in which the rankings were defined.

	0-1 Natural Rehabilitation	1-1 Chemical Stabilization	1-2 Clear Cutting Vegetation	1-3 Stumping and Grubbing	1-4 Scraping and Grading (<5 cm)	1-5 Shallow Plowing (<10 cm)	1-6 Deep Plowing (10 to 40 cm)	1-7 Soil Cover (<25 cm)	1-8 Soil Cover (25 to 100 cm)	2-1 Remove Plow Layer (10 cm)	2-2 Remove Shallow Root Zone (<40 cm)	2-3 Remove Scraping and Grading, Mechanically Stabilize	2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	2-6 Remove Scraping and Grading, Chemically Stabilize	2-7 Remove Plow Layer (10 cm), Chemically Stabilize	2-8 Remove Shallow Root Zone (<40 cm), Chemically Stabilize	3-1 Barriers to Exclude People	3-2 Barriers to Exclude Large and Small Animals	4-0 Mechanical Stabilization by Hard Surface	5-0 Application of Sewage Sludge	6-1 High Pressure Washing (<3 mm)	6-2 Flooding (3 to 30 cm)	7-0 Soil Amendments Added
LAND TYPES																								
Desert	4	2	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4	1	1	4	a	a	a	a
Prairie	3	5	5	5	1	1	1	2	3	1	1	1	1	2	1	2	3	3	3	3	a	a	a	a
Deciduous Forest	4	2	2	3	2	3	3	3	4	1	2	1	2	3	2	2	4	1	3	4	0	a	a	a
Coniferous Forest	4	2	2	3	2	4	4	3	4	1	2	1	2	3	3	3	4	1	3	4	0	a	a	a
Mountain, subalpine	4	2	2	3	2	4	4	3	4	2	3	1	3	3	3	3	4	1	3	a	a	3	5	a
Tundra	3	5	5	5	1	5	4	2	4	1	2	1	2	2	5	5	5	1	3	a	a	a	a	a
Coastal Inter-Tidal Marshes	4	3	3	3	3	5	5	2	3	3	3	2	2	3	4	4	4	1	3	a	a	a	a	a
LAND USE CLASSES																								
Agriculture	4	3	3	3	1	1	1	1	1	1	1	1	2	2	2	2	3	2	3	4	1	a	a	4
Suburban	4	4	4	4	3	4	4	2	4	2	4	1	1	4	2	2	4	3	3	5	a	a	a	a

a - Outside scope of work.

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INTRODUCTION

STATEMENT OF THE PROBLEM

In the industrialized development and commerce of today's technological society a variety of goods are transported by land, sea, and air. Among these goods in transit at any particular instant are some which are toxic or injurious to man coming into direct or indirect contact with them. Indirect contact includes drinking contaminated groundwater, consumption of plants that absorbed contamination from soil, and using dairy products or meat from contaminated animals.

Contaminating accidents may also originate when industrial processes malfunction. These include explosions at chemical process plants, inadvertent releases by plant operators, and a variety of other dumps or leaks.

The frequency of contaminating accidents has increased yearly until they have become an almost daily event. In most cases, the contaminant is spread by natural forces and human traffic during evacuation of the residents. By the time the contaminant is identified and the zone of contamination delineated, the contaminant may have penetrated environmental materials and decontamination may be required. The methods of decontamination are numerous and varied.

PURPOSE OF THE REPORT

This report is concerned with the ecological impacts of specific cleanup treatments on the land where they are carried out. The report provides guidance to rational selection among the cleanup procedures likely to be suggested by State, Federal or local government officials, industrial representatives of the entity responsible for the contaminating accident, concerned citizens' groups, or local environmental managers called in for their expertise. The priorities of these groups are most likely to be divergent and emotionally intense under the stress of immediate, local, present danger.

This report is intended to present the best unbiased, neutral estimate of how local environments will be changed by specific common cleanup treatments, the relative magnitude of the changes they may cause, and their duration.

Local conditions have the greatest force in determining how interrelated environmental actions occur. Therefore, the cleanup treatment to be used at a given site must be decided upon with input from local geologists, foresters, soil scientists, agronomists, botanists, dairymen, animal husbandmen, zoologists, or other professionals intimately acquainted with the contaminated area.

SCOPE OF THE REPORT

This report provides two classes of generic data that may be helpful in deciding what steps should be taken when contamination occurs.

A chapter is devoted to each of seven land types and two managed ecosystems in the United States. Generic descriptions are given in Part I for the seven land types and in Part II for the managed ecosystems of agricultural lands and urban/suburban areas. The vegetation of the seven land types is described in detail with brief descriptions of their climate and upper soil profile. The history of ecosystem recovery from natural and man-made catastrophes is reviewed as a guide to predicting how specific cleanup treatments will affect vegetative recovery.

The second class of information is the generic data arising from descriptions of the effects each of 24 specified cleanup treatments has upon the soils and vegetation in the affected ecosystems. This information includes a recovery scenario, quantitative assessment of cleanup impacts, and citing the best and worst treatments for each land type.

The purpose of the descriptions is to provide a general framework for coordinating information from which to predict both the short-term effects of cleanup and resultant long-term changes. Different plants succeed in different land types but all the plants lack a means of avoiding cleanup trauma. Whatever cleanup treatment is used will rearrange some of the soils and damage most of the plants in a heavily contaminated area. Land types and cleanup treatments were indicated by the EPA to be the items of major interest, and specific biota of lower level interest. Thus, defining the ways in which the soil-plant web subsequently develops over time after injury is the main thrust in the quantitative assessments.

After several attempts to describe faunal displacement and recolonization after cleanup in separate ecosystems it became obvious that excessive redundancy lay along that approach, in that animal families are adaptable to several ecosystems. To escape such redundancy, the major faunal groups are described and predictions made of their response in each disturbed ecosystem, and each managed land type, where they occur naturally. Part III presents material on two divisions of animal wildlife, the birds and the mammals. Animal families cross land types in the same context that cleanup treatments cross land types in Parts I and II of the report. Evaluation of the ecological impact of cleanup treatments was confined to mammals and birds. Ecological impact is defined as the reaction of a population to disturbance of their habitat by cleanup. The reactions considered were those large enough to be measured quantitatively under field conditions. The population attributes considered suitable for monitoring to define changes in the population were size (in numbers of individuals) and/or alterations in the numbers of species present in the area of concern. These attributes of populations were taken as representative of habitat stability for evaluating cleanup effects.

The critical component in population recovery of wildlife is the restoration of vegetative species suitable for the wildlife. The impact assessment tables presented in the chapters are based upon best estimates for vegetative recovery times, or productivity changes.

Almost any spot in the United States could be involved in a contaminant spill from some source. The seven natural land types chosen represent most of the United States. The land area of the United States, including Alaska and Hawaii, totals approximately 10,900,000 km^2 of which approximately 240,000 km^2 are measured as inland waters. The area not covered by water (approximately 10,660 km^2) can be measured as approximately 1,068,770,000 hectares, excluding public lands, and can be subdivided into the land types shown below. The percentage breakdown of the seven natural ecosystems and the two managed ecosystems follows (note that the land-use class of ecosystems overlaps the natural ecosystems):

Chapter	Land Type	Total land surface (percent)	hectares
	NATURAL ECOSYSTEMS		
1	Desert	0.4	4,168,000
2	Prairie	49.8	532,567,000
3	Deciduous Forest	28.9	309,302,000
4	Coniferous forest	7.4	78,875,000
5	Mountain	8.7	93,090,000
6	Tundra	4.4	47,133,000
7	Coastal Inter-tidal	0.3	3,634,000
	LAND-USE CLASSES		
8	Agriculture	45.4	485,328,000
9	Urban/suburban	7.7	82,509,000

The areas examined for cleanup range from a hectare (the size of a country home) to approximately 4 sections of land, which is not large for a typical dryland grain farm but is approximately the mean area of a county. In metric terms, these areas are 0.01 km^2 and 10 km^2, respectively. Intermediate areas 0.10 km^2 and 1.0 km^2 are also addressed.

The time scales for which cleanup impacts are defined range from short term (a few years) to those times when the cleanup is no longer visible (hundreds of years). An arbitrary cutoff point at 100 years was imposed in determining whether a treatment was acceptable. If more than a century is required for recovery, the treatment is considered unacceptable.

LITERATURE BASE

More than 400 publications are cited in the report and approximately 3,500 others were retained for inspection and discarded. Personal contacts with other professionals in the areas addressed were made freely. The preferred data base is included in this report.

STUDY APPROACH

The assembled study team was comprised of professional ecologists actively engaged in field work in the land areas to which they were assigned for this project. All were familiar with environmental impact assessment methodology and the professional literature in their fields.

The ecologist constructs a mental model of the ecosystem climate, geology, soils, vegetation, and animal forms and predicts the ecological impact of cleanup operations. Published observations are reviewed to develop an outline of the ecological boundaries of the ecosystem developed on the land type being studied. When published literature was inadequate or absent, personal experience was used to predict the impact of cleanup treatments on the ecosystem being described. The impact predictions in Sections 4 and 5 of each chapter represent a blend of the published data and personal experience. The predicted onset of recovery appears in Section 6 of each chapter and presents the quantitative assessment for the impact forecasts in Section 4.

Contamination cleanup has been postulated in this report to occur only in land type tracts that support recognized and developed ecosystems where recovery following cleanup progresses along secondary succession, rather than ecosystem development by primary succession (new substrate occupied, such as earthquake uplift scarps).

In considering the sequence in which cleanup treatments should be addressed, it became obvious that the intensity of environmental impact of a specified cleanup treatment varied from land type to land type; e.g., surface grading a shallow soil layer on grassland was less disruptive than cutting the same depth and width through a forest. Arbitrarily, a uniform sequence and presentation of cleanup treatments was maintained throughout the report for the sake of continuity. Those persons interested in following a specific treatment through all land types are advantaged by this methodology, hopefully with little disadvantage to those persons intent on examining ecologic impacts within particular land types.

Cleanup treatment impacts were ranked across all land types according to the gross environmental disturbance they would generate. The disturbance was translated into "median years-to-recover," presented in relative times to recovery (recovery indexes), and tabulated in Section 6 of each chapter. Details of these derivations are given in Appendix B.

The endpoint of recovery from cleanup for the prairie, deciduous forest, and coniferous forest is ecological: the reestablishment (succession) of the original species of plants and animals at the pre-contamination productivity (biomass). Six of the chapters deal with ecosystems which do not have identifiable succession and a different concept of endpoint is used in those chapters. The four chapters of desert, mountain, tundra, and marshes use "years-to-recovery" of their pre-contamination productivity (biomass) as the terminal point of rehabilitation. In the managed ecosystems of Chapters 8 and 9, the recovery endpoints are determined by economic productivity and public acceptance, since physical recovery can be expedited via use of machinery. The concept of ecological rehabilitation is inappropriate in these managed ecosystems because they lack the attributes of succession.

IMPACT EVALUATION

The equipment projected to be used for cleanup was limited to that operated by small contractors or to farm machinery. The technical evaluation steps are shown in Appendix B as a sequence of steps. Where data were sparse for an ecosystem, the author integrated his field experience with published data to construct the tables prepared for individual chapters.

Idealized trend curves were developed for Section 5 in many ecosystem chapters to illustrate the time course of recovery to full productivity for some of the descriptive ecosystem parameters. The ordinates are without units either because they have no dimensions (e.g., homeostasis) or they are broad generalizations over an array of heterogeneous sites. Representative types of cleanup treatments were selected for the illustrations to indicate the variety of parameters common to particular ecosystems.

USE OF THE REPORT

The report is subdivided into 3 Parts and 5 Appendices. In Part I seven natural ecosystems and some of their natural derivations are defined. Part II presents managed ecosystems which are imposed on natural ecosystems and are no longer bound by the initial native ecosystem balances. Part III deals with avian and mammalian wildlife displaced by cleanup. Appendix A summarizes judgments of stabilizer chemicals and their application to various land types. The methodology used to derive recovery indices for those ecosystems having easily recognizable successions is presented in Appendix B. Appendices C, D, and E, respectively, give definitions of the land types studied, cleanup treatments considered, and a glossary of terms.

Each chapter in Parts I and II is divided into seven sections. The first three sections give ecologic data sources used in evaluating the cleanup impacts. In Sections 2 and 3 the ecological basis is given for the judgments utilized in Sections 4, 5, 6, and 7.

Each cleanup treatment is defined in Appendix D and the impact of each is defined in Section 4. Section 5 gives a brief scenario of how the ecosystem is envisioned to change between cleanup and the time at which no further changes are measurable within present detection instrument capabilities. Quantitative assessments of the magnitude of cleanup impact are made, recovery time predicted, and the effects of using the cleanup treatment on larger areas evaluated. In Section 7, the cleanup treatments that are best suited to the ecosystem are named, as are those which are inappropriate.

Agricultural uses of ecosystems modify the basic characteristics beyond the capabilities of native forces to change them on a short-term basis. The modified ecosystems are evaluated in Chapter 8 separately from their parent ecosystems. Urban/suburban landscapes also bear few recognizable imprints of their ecosystem origins and are described in Chapter 9 as a unit of managed ecosystems.

For nonecologists who desire an accurate but direct presentation of the essence of ecology, the paperback book, "Communities and Ecosystems," by R. H. Whittaker, is recommended. In general, the ecosystem is viewed as following a definite sequence of recovery with time that is predictable, called succession. As the cleaned up ecosystem enters into natural recovery, the initial small, short-lived invader species is gradually replaced by long-lived and larger species which tend to exert more and more control over their surroundings. An example is the high-himidity understory of park-like dimensions which has developed under beech-sugar maple in the deciduous forest zones. The collective steps in recovery which follow one another are called the sere and its use in this report is illustrated in Appendix B. Formal classical ecologists will doubtless object to this abbreviated presentation on the grounds that it is "applied ecology."

This report was written to summarize what is known and published in technical journals, books, and reports about how cleanup affects the environment. Unfortunately, the published data fall far, far short of being continuous in both time and in the consecutive details of recovery. References are cited where information is derived from the literature; if no reference is cited, the information is the author's own projection of the recovery after cleanup is completed.

The ecosystems in Part I are described in terms of recovery from cleanup without additional interference or assistance by man. The kinds of assistance that are appropriate to perform on three of the ecosystems are collected into the Agriculture chapter in Part II because these are the land types that produce the commercial foods and fiber at the greatest rates.* The reclamation processes that are appropriate after plowing—irrigation, reseeding, transplanting, fertilizing, contour tilling, and harvesting—are widespread management practices of agriculture. These are presented in Chapter 8 only to a limited degree since this report deals with cleanup impacts—not with impact erasure. Discussion of these management practices within ecosystem chapters has been restricted to special cases that are unique to natural systems.

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*These three land types are desert (Chapter 1), prairie (Chapter 2), and deciduous forest (Chapter 3).

CONCLUSIONS

Cursory inspection of the conclusions sections of the chapters shows that generalization and condensation to produce a single conclusion for the report is not effective. The most disruptive technique was concluded to be paving over a compacted subgrade. However, estimates of the time for this to be weathered and assimilated differ among ecosystems. The general conclusion about ecosystems was that succession was relatively unchanged by a variety of techniques that assisted in early and rapid revegetation. Mulches, stabilizers, plowing, and fertilizers were very effective in reintroducing new growth but the particular ecosystem controlled which species would succeed into climax. Plantings of hardwoods in grasslands or coniferous ecosystems would have no effect on the time to climax or eventual climax species, although grasses are most likely to provide early cover in any of the widespread ecosystems.

This report has addressed the impacts of particular cleanup techniques on specified ecosystems but other areas of study remain. The effectiveness of cleanup techniques in removing or stabilizing contamination needs to be addressed. The greatest need is the development of a methodology to quantify (into monetary terms) the information collected on environmental impact.

PART I

NATURAL ECOSYSTEMS

CHAPTER 1, DESERTS
CHAPTER 2, PRAIRIES
CHAPTER 3, DECIDUOUS FORESTS
CHAPTER 4, CONIFEROUS FORESTS
CHAPTER 5, AEOLIAN MOUNTAIN PEAKS
CHAPTER 6, TUNDRAS
CHAPTER 7, COASTAL INTER-TIDAL MARSHES

CHAPTER 1
DESERT

1.1 OVERVIEW

There is little accord among scientists as to what constitutes a desert. It is generally agreed that sparse to absent vegetation due to little rainfall is the distinguishing feature, but where some scientists limit the definition of desert to areas receiving less than 50 mm of rainfall annually, others include regions with 360 mm of annual rain, or even more. In addition, it is recognized that the rainfall amount alone is not the primary determinant of desert type, but that seasonal moisture fluctuation, temperature, and edaphic factors are also important. For example, the polar regions are true deserts because they lack vegetation and exhibit low levels of atmospheric water vapor. There are also regions of the world which receive in excess of 300 mm of annual precipitation but are dry, barren and relatively devoid of vegetation. Such regions are termed edaphic deserts because the physical cause of aridity is in the nature of the porous surface soil which allows moisture penetration at a rate too rapid to permit plant sustenance regardless of the amount of rain that may fall.

The focus in this discussion is on the desert of North America, specifically the desert of the United States. This desert is a large irregular belt on the western side of the continent covering about 940,000 square kilometers from mid-Idaho to Northern Mexico and roughly corresponding to the rain shadowed intermontane region between the coast ranges and the Rocky Mountains. It includes major parts of the states of Arizona, Nevada, Utah, and lesser parts of California, Colorado, Idaho, New Mexico, Oregon, Texas, and Wyoming.

The physical geography and human utilization of the region exhibit great internal variety, but its overall aridity associated with an excess of evaporation over precipitation, high percentage of sunshine, great temperature extremes, high diurnal air temperature, low atmospheric humidity, frequent winds and a predominance of eroded landscapes give it an unquestioned unity. In general, the region is characterized by rainfalls less than 250 mm per year. In these areas the environmental gradients are altitudinal gradients, where temperature decreases and precipitation increases with elevation. Desert communities occupy the lowest, driest areas and juniper and piñon-juniper woodlands are on the higher more mesic regions. The eastern and northern boundaries merge into grassland prairie. An intermediate land type, the desert grassland, will also be briefly discussed.

In this report, areas receiving 250 mm or less of rain per year will be classed as desert. The peripheral desert grasslands receiving somewhat greater annual moisture will be called arid areas. This is not an arbitrary classification but rather one based on the requirement for unassisted revegetation. Moisture is the dominant factor in vegetation growth and it is generally conceded that once relatively large areas of vegetation have been destroyed, about 250 mm of rainfall per year is the minimum needed for revegetation without supplemental irrigation.[39,51,60]

In the discussion below are considered the climatic, edaphic and topographic features which explain a desert, and the vegetative factors which characterize it. The goal of this summary is to form a basis for understanding the effects produced by natural and anthropogenic (man-made) environmental perturbations.

1.1.1 Desert Climate

Geographers have attempted to classify desert types by climates, usually in terms of precipitation and temperature and their seasonal variation. The basis for the most widely used classification scheme is the Köppen system which is based on distribution of vegetation.[42] Vegetation is sensitive to temperature and precipitation and tends to reflect these variables in a general way. Because aridity, the distinguishing feature of desert areas, is a measure of dryness, an index based on water balance of an area would be superior to the Köppen system for a climatic analysis. Meigs,[49] building on the indices developed by Thornthwate[91] which were closely reflective of water balance considerations, formulated a classification scheme which includes a more explicit appreciation of the role of evaporation, storage of moisture in the soil and the seasonal variability of precipitation. The Meigs classification uses season of rainfall, maximum temperature of the hottest month and minimum temperature of the coldest month to differentiate arid areas.

Based on Meigs' considerations of climate, the American Desert can be divided into four regional districts.* The northernmost of these, the Great Basin, has cool or cold winters, frequent snowfall and annual precipitation ranging from 100 to 220 mm of which only about 40 percent falls in the summer months. In the southern part are the hot deserts: the Mojave, with winter rains; Sonoran, with summer and winter rains; and Chihuahuan, with summer rains. The Chichuahuan is somewhat isolated but the other three lie in a continuous series.

In general, the temperature of the North American desert increases toward the south while total precipitation decreases. In any given latitude, precipitation increases both east and west of about the 115° meridian. The frequency and amount of precipitation vary directly as a function of elevation with elevation accounting for about 80 percent of the variance in rainfall statistics. The southwest corner is the hottest, driest desert area.

A curve of precipitation amount plotted against time of year for desert areas is characteristically bimodal, with peaks in the winter and summer. The relative dominance of one peak or the other has profound influence on the ecology of the areas. Orographic barriers are largely responsible for affecting the seasonal distribution of rainfall in the cool Great Basin desert. This area lies in the zone of westerly cyclonic storms but much of the moisture in these storms is extracted by the western boundary mountains. These storms bring much of the annual precipitation during the winter and early spring months. In the hot deserts to the south, two major climatic influences cause different seasonal patterns of rainfall. In the eastern part, the Chihuahuan and to a lesser extent the eastern Sonoran, the major rain is during the summer. This summer rain results from a seasonal shift in global weather patterns which cause moist air from the Gulf of Mexico to be drawn over the area. Convective precipitation originates in this moist air mass. The western extent of this effect is about the Arizona-California border. To the west of this line, the Mojave receives winter rain from frontal systems of the cyclonic storms from the west or north. Only rarely does summer rain, usually from moist air from the Gulf of California, fall in this area. The Mojave is the driest of the areas, with some locations reporting only 50 mm of rain a year. As a rule, the lower annual average rainfalls are associated with higher variance from the average.

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*The nomenclature for the desert areas is based on work by Shreve.[78]

It is important to recognize that the frequency and intensity of rain are important ecological variables.[37] A summer rain totaling 150 mm in a given locality might be the result of one or two rains during the season, perhaps with a duration of two to three hours for each rain. Beatley[5] has shown that in Mojave desert ecosystems, heavy (>25 mm) rainfall triggers phenological events. There is a predictable relationship between early winter heavy rain and successful vegetative and reproductive growth of shrubs the next spring. Productivity of desert plants is directly related to the distribution and numbers of desert animals.[7] However, in deserts, where small differences in the amount of moisture are of great significance, the numerical relations among species are not consistent from year to year or necessarily correlated with seed supply.[89]

The climatic division of the American deserts into hot and cool temperature regimes and into summer, winter and intermediate precipitation patterns is reflected in the classification and existing distribution of desert vegetation, but the recovery potential of an area will be an interaction between available moisture and local soil conditions.

1.1.2 Soils

An ecosystem typically consists of a complex mosaic of overlapping patterns that reflect, within the limitation of time and local materials, not only present but past patterns of distribution of biota. A soil profile adjacent to a Mesquite (*Prosopis juliflora*) or to a creosote bush (*Larrea tridentata*) may differ markedly from a profile 2 meters away on barren ground. However, the major soil type of almost all desert areas is similar. The basic characteristics are coarse texture; an accumulation of carbonates within a few feet of the surface contributing to the formation of a hardpan or a caliche layer; and low organic matter content.

The United States Comprehensive Soil Classification System[83,84,85] classifies the soil order underlying almost all of the American deserts as Aridisols. Soils of other orders, especially the Entisols, are also present but less extensive in deserts. The Aridisols at the northern edge of the Great Basin Desert are replaced by Mollisols.

Shantz[70] has noted that regions defined as arid by geographers cover an estimated 43 percent of the world's land area; however if defined on the basis of climate, arid regions occupy only 36 percent of the earth's surface, 35 percent if defined on the basis of vegetation, but Aridisols cover only about 25 percent of the surface. Thus, worldwide regions of soils classified in the Aridisol order do not conform to all the parameters of either climatic or vegetation zones.

The Aridisols, formed under low rainfall, are leached little and are therefore high in calcium, magnesium, and other soluble elements. Desert soils seem particularly subject to the formation of impervious surface layers—either by physical processes or through the surface development of algae and lichens—so that the effective drought is accentuated by excessive runoff. The Aridisols are usually dry and are never moist as long as 90 consecutive days during a period when temperature is suitable for plant growth. The low rainfall also limits plant growth so that the soils are low in organic matter and have low carbon/nitrogen ratios. The soils are young in profile development and show little evidence of leached upper horizons. The combined A and B horizons are frequently less than 30 cm thick. As a rule the A horizons are light colored whereas B horizons are similar or slightly darker in color. The C horizons are light-colored and usually calcareous. All horizons are neutral or mildly alkaline.

Entisols are of such recent development that no horizons have formed. They are most extensive on steep actively eroding slopes or alluvial fans where the rate of sedimentation is high.

Mollisols contain a thick A horizon high in humus and a base of calcium or magnesium. In the northern Great Basin Desert they are formed under vegetation consisting chiefly of grasses. The climatic regime is moist in winter and dry more than 60 consecutive days in summer.

Much of the diversity in soil profiles reflects their origin. Coarser fragments are found in soils developed nearer the base of mountains and hills, and finer textures are found toward the middle valleys. Clay, if present, is usually found in the B horizons in more level areas. Carbonate content of soils is usually closely correlated with the origin of parent material, and is highest in areas immediately adjacent to limestone mountain ranges. High carbonate concentrations are almost always correlated with the presence of a restrictive hardpan. Low carbonate soils are most often developed on alluvium of mixed igneous and sedimentary rocks.

The particle size distribution of the soils also reflects formation of alluvial deposits. Variation in texture is largely due to differences in distributions of sand and silt particle size fractions. At low elevations there is characteristically a low clay content, but increased clay concentrations are found on alluvial sediments in closed drainage basins.

The climatic regime in which Aridisols form is characterized as one in which precipitation is less than evapotranspiration during most of the year and no water percolates through the soils. This has two important consequences. First, horizons of soluble salts underlying calcium carbonate and gypsum are normally found at the average depth of water penetration. This depth will be important in relation to the consequences of a given depth of soil removal. Second, since rainfall is seasonal, there will be periods when precipitation is in excess of evapotranspiration and water will be stored in the soil to be used in the spring or fall growing season. Thus, the time of year in which a postulated cleanup takes place relative to the seasonal characteristics of rain in that area is important for predicting ecosystem response.

There is ample evidence of accelerated soil-forming processes under desert shrubs. The highest concentrations of organic carbon, organic nitrogen[52] and available phosphorus[66] occur in the upper horizon under shrubs. Salts also accumulate under shrubs, probably through litter decomposition from leaf fall, although Odum noted that microbial decomposers would be limited by dryness.[54] (Odum speculated that rodent herbivores were important in this aspect of nutrient cycling.) In the transition zone between the Mojave and Great Basin deserts, the average carbon/nitrogen ratios have been determined to be about 10 while in the A horizon under shrubs, values between 12 and 15 are common (the range was 5-30). Only in the A horizon did organic carbon content exceed 1 percent. These low C/N ratios could be due to low organic matter of desert soils, an increase in nitrogen fixation, or a combination.[66] Nitrogen fixing Azotobacters are usually few or lacking on desert soils.[47] Other differences in soils under shrubs are noted: soil pH tends to be lower, conductivity of saturation extracts higher, nitrates and chlorides accumulate more and exchangeable cations are greater.[66]

Algae and fungi grow in and on the soils contributing to fixation of atmospheric nitrogen and to soil stabilization by forming crusts.[21] These crusts attain a thickness of 2 to 3 millimeters and are sufficiently tough to permit their removal from the soil surface as a film. They may result in considerable water runoff by sealing soil surfaces or they may result in improved water-holding capacity. In addition to stabilizing the surface of cohesionless soil, algae can add considerable quantities of nitrogen to the soil through their nitrogen-fixing ability.[73] Soil fungi may be necessary in nutrient cycling. Symbiotic mycorrhizae, root fungi, associated with the white bursage Ambrosia and the grass Hilaria rigidu are necessary for phosphorus absorption in soils with low available phosphorus.[97]

1.1.3 Topographic Factors

The effects of altitude on temperature and precipitation have been determined in many desert localities. There is an average decrease of 1°F for each 100 m rise in elevation but the rate varies with the season of year and with local conditions.[88] South slopes at a 90° angle to the sun receive 1.5 times as much heat as level areas. Shreve[80] listed the principal features of altitudinal climatic change as:

1. shortening the frostless season
2. lowering the daily curve of temperature throughout the frostless season
3. increasing the intensity and duration of all critical phases of low temperature during the frost season
4. shortening the arid fore-summer, a critical period
5. increasing rainfall and thus soil moisture
6. decreasing evaporation.

Beatly[4] showed the importance of local topography on vegetation distribution. Low temperatures resulting from downslope drainage of cold air into closed basins coupled with differences in seasonal precipitation resulted in anomalous vegetation mosaics at the transition between the Great Basin and Mojave deserts.

A second effect of local topography is its relationship to rainfall. On flat or gently sloping surfaces, rainfall leads to unconcentrated flow over large areas, with thin and extensive sheets of moving water, known as sheetflow. This results in the removal of a thin layer of soil from the entire surface. Generally only the smaller soil particles are removed, to be deposited in low lying areas. Naturally rill and gully erosion occur also, and a distinctive feature of desert areas is the erosional pattern.

1.1.4 Vegetation

The climatic divisions of the American desert of Meigs correspond very well with the four regional deserts described by Shreve[78] and shown in Figure 1-1. In each of these regions further subdivisions into mosaics of vegetation types are made by plant association communities which are distinguished by distinctive combinations of dominant species. Desert perennial plants grow both singly and more often in clumps, separated by bare areas of desert soil. Often a clump of vegetation contains more than one species of plant; as many as 10 different species have been recorded from a single clump.[81] The size and spacing of the clumps are irregular. Some plants, such as creosote bush (*Larrea tridentata*) thrive in several desert areas but other plants are restricted almost exclusively to a particular desert region. These indicator plants are:

Great Basin — Sagebrush (*Artemisia tridentata*)
Mojave — Joshua Tree (*Yucca brevifolia*)
Sonoran — Saguaro (*Cereus giganteus*)
Chihuahuan — Agave (*Agave lechuguilla*)

1.1.4.1 Great Basin Desert--

Numerous mountain ranges are scattered over the Great Basin resulting in a sharp vertical zonation of the plant life culminating in either a xeric or a mesic forest cover on the range tops. The actual desert occupies the floors of the detrital valleys.

The vegetation is a monotonous open shrubland with almost no cacti or large plants. A distinctive feature of the vegetation is the predominance of communities which are very simple in composition or have as much as 95 percent of their stand made up of a single species.[82] The commonest dominants are shadscale (*Atriplex confertifolia*), sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus spp.*), blackbush (*Coleogyne ramosissima*), and winter fat (*Eurotia lanata*). Open stands of greasewood (*Sarcobatus vermiculatus*) are found on the saline flats. Indian rice grass (*Oryzopsis hymenoides*), indigo bush (*Dalea spp.*), fourwing saltbush (*Atriplex canescens*) and a number of

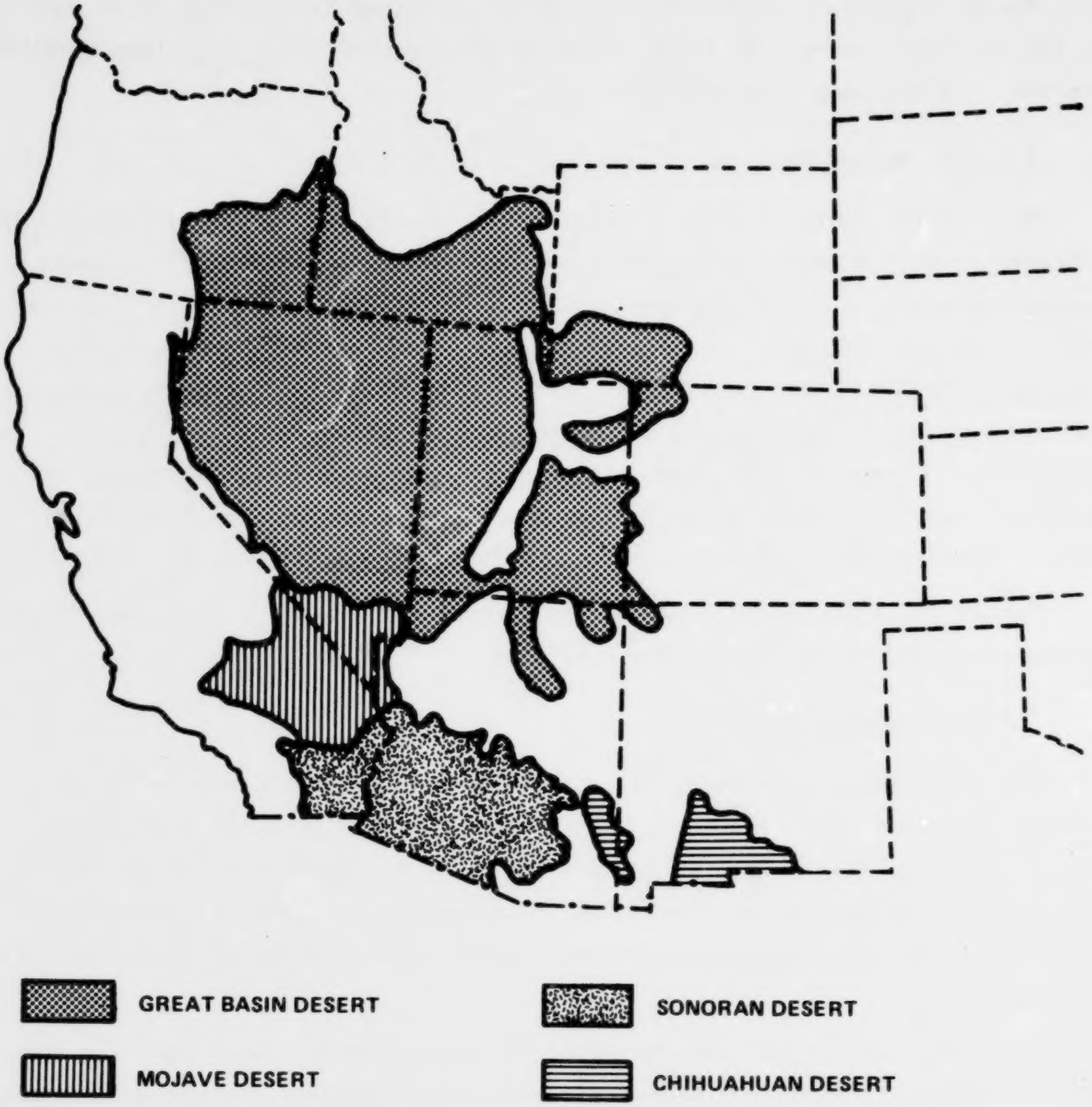
GREAT BASIN DESERT
SONORAN DESERT
MOJAVE DESERT
CHIHUAHUAN DESERT

Figure 1-1. The North American Desert and its subdivisions (after Shreve[78]).

herbaceous plants and perennials are also found. Shrub coverage averages 24 percent in the various associations, with a range of 15 to 37 percent.[4]

The precipitation in several localities is higher than in any other part of the American desert. It ranges from 100 to 270 mm. The winter temperatures are low, and frequent snowfalls occur.

1.1.4.2 Mojave Desert--

This is the smallest unit of the American desert and lies almost wholly in California, with a small wedge extending into both southern Nevada and northwestern Arizona. Its elevated margins are delineated by the range of the Joshua Tree (*Yucca brevifolia*). The bajadas are mostly dominated by creosote bush (*Larrea tridentata*), but communities of four-wing saltbrush (*Atriplex canescens*) and complexes of *Grayia-Lycium*, *Lycium shockleyii* and *Ambrosia dumosa* are extensive. On the northern edge *Coleogyne ramosissima* and *Grayia spinosa* are dominant. Shrub coverage averages about 16 percent ranging from 7 to 23 percent.[4] More spring ephemerals are found because of the mild, moist winters.

Annual precipitation decreases from 125 mm on the west to less than 50 mm on the east, and occurs during the late winter.

1.1.4.3 Sonoran Desert--

The subtropical Sonoran is the most varied of the American deserts and exceeds the other three deserts in the number and variety of its life forms. The desert lies between sea level and about 1,000 m. Above this upper limit are isolated mountain masses that, due to orographic factors, can receive as much as 700 mm of precipitation per year yet be located within a short distance of *Larrea* plains.

More than half of the Sonoran Desert is dominated by plants with a stature of less than 1.5 m. Almost pure stands of *Larrea*, *Ambrosia*, *Lycium* and *Atriplex* are found. *Larrea* and *Ambrosia* dominate the lower portion of the desert but they are joined by many shrub, tree, and succulent subdominants which become more and more prominent toward higher elevations and greater rainfall. Often two species, or sometimes three form the entire vegetation of an area. On plains and bajadas below 300 m elevation the total perennial flora rarely exceeds 10 species.[82] The most prominent cactus is the saguaro (*Cereus giganteus*). Barrel cacti (*Echinocactus spp.*), hedgehog cacti (*Echinocerrus spp.*), and prickly pears (Opuntia spp.) are common. Small legume trees such as palo verde (Cercidium floridum) and C. microphyllum) and ironwood (Olneya tesota) are prominent. Ephemerals are of two kinds, spring and summer flowering because of the bimodal rainfall pattern characteristic of the Sonoran.

As Shreve[82] notes,

> "With the prevailing simplicity of composition, it follows that the entrance or exit of a single species, or a great change in the relative abundance of two or more species, may make a profound change in the physiognomy of the vegetation."

Precipitation ranges from almost nothing to 300 mm on the eastern edge.

1.1.4.4 Chihuahuan Desert--

The easternmost of the American Deserts is the Chihuanhuan Desert in the United States covering part of New Mexico and Western Texas adjacent to the Rio Grande. A large island of Chihuahuan Desert flora occurs along the San Pedro Valley of Arizona, well away from the main body of the parent desert.[78]

The Chihuahuan is separated from the main part of the American desert and makes no contact with other desert regions. To the north and east it grades into semiarid prairie; while to the west the Continental Divide separates it from the Sonoran Desert. Larrea, common to the Mojave, Sonoran and Chihuahuan, is not continuous across the grassland that lies along the Continental Divide.

The prevailing plants are low shrubs, Larrea, Acacia, Prosopis or long leaf succulents, Agave lechuguilla, and Hechtia. Several species of Yucca and infrequent cacti Opuntia are also found. Dominance is shared by shrubs, succulents and semisucculents. The vegetation is most lush in the warm season, and there are no winter and early spring ephemerals as in the other deserts.

Precipitation ranges from 70 to 500 mm, and about 80 percent falls between the middle of June and the middle of September. Winter temperatures are low, with occasional periods of 30 to 72 hours of freezing.

1.1.4.5 Desert Grassland--

This arid biome is considered in this chapter because the southern section forms a division between the Sonoran and Chihuahuan deserts and because some areas now classified as desert were once this grassland. (The northern and western edges of the Great Basin Desert merges into the Palouse prairie[98] of western Oregon and Washington. Recovery in this area is similar to that of the short-grass prairie detailed in Chapter 2.) Shantz and Zon[72] believed that precipitation greater than 300 mm per year was required to establish and maintain the Aristida-Bouteloua grassland.

The desert grassland has undergone significant changes in recent years. In some locations grasses have been supplanted by shrubby vegetation, mesquite, acacias and burroweed. Clements[19] believed that much of what is now desert was once grassland before overgrazing destroyed the grass, but more recent studies emphasize the interaction of overgrazing with climatic change.[35]

In the remaining Desert Grassland, annual precipitation ranges from 300 to 400 mm, with summer moisture slightly exceeding that of winter.

1.1.5 Desert Succession

A desert ecosystem is obviously not a static system, but usually tends to approximate a dynamic equilibrium or to fluctuate around a stationary state. An ecological climax is an example of that dynamic equilibrium and the process by which the equilibrium is reached is termed succession. In order to understand the effects of some environmental disruption, it is clearly important to distinguish equilibrium systems from those that have not yet even approximated steady state. Equally important is to identify differences that may exist between exceedingly slow changes, which are hardly distinguishable from the equilibrium state, and changes that are more or less rapid. The rate of change is as fundamental for the concept of ecological succession and development as is the question of whether the climax equilibrium actually exists.

The concepts of climax and succession in desert areas will be reviewed in the next sections of this chapter by identifying the empirical observations of changes that have resulted from natural and man-caused environmental perturbations.

A caveat is required first however. It is not universally agreed that succession occurs in desert environments; if by succession it is meant that each of a sequence of communities alters or modifies the physical environment to be favorable for the next member in the sequence. Shantz[71] considered succession to be important as a basis for recognizing and understanding plant communities. Other arid land investigators, notably Clements[19,20] and Allred and E. Clements[1] stressed plant succession. However, the primary interest of these writers was in arid lands, not deserts. Shreve[79] cautioned about applying the succession concept to deserts:

> In a consideration of the dynamic aspects of the vegetation of the region in which the initial, sequential and final stages of a succession are characterized by the same species, and often by the same individuals, it is doubtful whether these conceptions, formed in regions with a very dissimilar vegetation, are of much real utility.

Muller[50] was in general agreement and found no seral succession in recovery of disturbed Chihuahuan Desert. Muller also noted that often the definition of climax and the seral stages leading to it are made to narrow that very little of the earth's surface may be said to be in climax condition.

Some features of recovery and succession after the proposed cleanup procedures are qualitatively similar to ecosystem recovery after natural or man-induced vegetation changes which have been documented for desert areas. These features are presented in the next sections.

1.2 NATURAL PERTURBATIONS

1.2.1 Natural Processes

Succession on naturally disturbed desert habitats such as washes which are periodically scoured by floods, actively eroded bedrock areas, or flood deposition on bajadas, has been studied little. Wells[99] noted that the characteristic shrubs of these natural disturbed areas, Thamnosma, Hymenoclea, and Salazaria, can be established in man-made disturbed areas and play a role similar to that of pioneer successional plants of more humid areas.

Campbell has described natural vegetation succession in wind-formed hollows (blowouts) between mesquite dunes as following five sequential stages.[15] The sequence only operates during a succession of favorable, i.e., wet, years. (The major mesquite growth is in the spring when other perennials are practically dormant.) The first stage is the Mat Stage. If moisture has accumulated in the blowout, species with a prostrate habit such as Tribulus become established. If moisture continues, either in the same or the following growing season a Weed Stage begins, Ambrosia for example. This stage results in a gradual decline in sand movement as the root systems develop. The third stage is the

Gutierrezia Stage, usually in the following growing season. At this point all of the plants of preceding stages are found. Together they have a generalized drought-resistant root system. Wind and sand erosion is reduced and leveling of the dunes along with sand deposition in the blowout area begins. If two or three years of above-average moisture have occurred the Sporobolus Stage of grasses begins. This is followed by a Bouteloua climax. Succession to the fourth stage requires three to four years of ample rainfall. No estimate was given of the time to climax.

Muller studied succession, or rather a cyclic phenomenon, in a Larrea-Ambrosia association in the Chihuahuan Desert.[50] In this area erosion removed the climax association and all existing soil down to a clay hardpan. Muller noted that succession, indeed plant growth, could not occur until the clay weathered and until a few inches of sand and gravel were washed from adjoining plains. The general sequence of recovery noted was shallow rooted grasses, sparse shrubs tolerant of a slight soil covering over the clay, dense shrubs as the soil deepened, sparse representations of Larrea, the climax association. No time for this process was given. At the time of climax all the species of all of the stages were present leading Muller to reject the idea of succession in desert scrub.

1.2.2 Fire

Fire is known to influence desert plant distribution. Controversy exists regarding the role of fire in maintaining desert grasslands, that is, the desert grassland may be an artificial biome (a disclimax) initiated and maintained by man. If this is true, artificial manipulation of deserts might result in grassland. Numerous writers[68,87] have hypothesized that grasslands are a product of repeated fire set by primitive man. Humphrey[40] among others[9] has applied this hypothesis to desert grasslands, largely on the historical evidence that areas now desert were formerly grasslands, which through a combination of overgrazing and fire suppression continued to desert climax. The theory says grasslands were maintained by frequent fires which prevented establishment of seeding shrubs. Once the sequence of fire was broken, by overgrazing and fire suppression, seed bearing shrubs became established and a self-perpetuating, irreversible vegetation change began.

The incidence of fire in the past compared to the present is a critical point. The controversy has been reviewed by Hastings and Turner[35] who conclude after examining travel journals of 22 early explorers that fires did not occur frequently in the desert grassland in the past—although it is noted that fires may have been locally important. They cite other factors which will be discussed later as cause of the decrease in size of desert grasslands.

There is an extensive literature of the effects of burning on desert vegetation. Although these studies report intentional man-caused fire rather than natural perturbations, they will be discussed here. The major thrust of these studies was range improvement by using fire to remove undesirable brush and allow grass and palatable forage species to grow. (This work shows implicit belief in the fire theory of desert grasslands.)

The results appear to be contradictory. Humphrey[41] found that burning prior to the spring rains killed burroweed (Haplopappus spp.), partially controlled mesquite and favored perennial grasses. Pickford[57] in the Great Basin desert found that burning destroyed sagebrush and allowed grasses to increase and a more recent work[55] indicates that forage species and grasses are increased about 70 percent three years after burning. Reynolds[61] obtained conflicting results for a June burning of Great Basin vegetation. The density and productivity of the area were reduced and remained below control areas for three growing seasons. The first year productivity was down 50 percent and the next two years down 10 percent. The treatment did kill 90 percent of the burroweed, half the cholla, and one-quarter of the prickly pear.

Longstreth and Patten[46] have developed a model which postulates a number of interacting factors that result in increased water and nitrate loss as brush is converted into grassland. The loss of soil nitrate would result in decreased productivity which agrees with Reynolds observations. It has been noted that on heavily grazed ranges fire had little effect on the proportion of grasses to forbs, but on lightly grazed ranges fire significantly reduced grasses and increased forbs.[36] This also might explain some of the conflicting results noted of the effectiveness of brush burning on range improvements.

The effects of fire are not permanent. The perennial vegetation of many desert plants resprouts from the root crown of a pre-fire plant, then grows at the rate normal for the plant species. The time for complete recovery is unknown; however 40 to 50 years, about 1/2 of the life span of desert plants, may be a good estimate.[17,96] Range reclamation experts recommend three to five-year intervals between burnings to minimize undesirable species, but no indication is given of the amount of recovery to the pre-burn condition during this time. Beatley[7] measured vegetation parameters on adjacent burned and unburned plots in Grayia-Coleogyne and Coleogyne associations in the Mojave-Great Basin transition. The plots had been burned 13 and about 22 years prior to her study. The burned areas were quite distinctive and easily seen in the vegetation mosaic. The cover of herbaceous perennials in the burned area was only 20 percent that of unburned plots; however, winter annuals increased by a factor of 2.5 and grass (Bromus) was increased by a factor of 3 in the burned plots.

Pechanec recommended burning of sagebrush range in the late summer or early fall after the seeds of perennial grasses had matured.[56] The spring was recommended by Semple as the best time to burn, for then the soil is damp and losses of organic matter were not likely to be great.[69] The principle appears to be avoidance of detrimental effects on the perennial seed.

Piemeisel[58,59] made detailed studies of the early stages of secondary plant succession after fire in the Great Basin desert. He notes that the original sagebrush dominated cover was exceedingly complex. The community was composed of perennials with bulbs, tuberous roots, and rhizomes and perennials forming mats, rosettes and tussocks. Most growth is made between October and July; the time of autumn rains and the beginning of the next hot summer. Growth is interrupted by winter cold and terminated by summer heat. The annuals grow in spring and summer. The successional order is first Russian Thistle (Salsola spp.), then mustards (Sophia parviflora or Norta altissima), then downy chess (Bromus tectorum). These successional changes usually take place within five or six years. Grazing by livestock or rodents may result in holding the vegetation at one of these lower stages and retarding or preventing the reestablishment of perennials.

1.2.3 Climate

Long term climatic fluctuations which influence vegetation are well documented. For example, a synchronous change from juniper and pine woodland to desert grassland occurred about 8000 years ago in the Mojave, Sonoran and Chihuahuan deserts, probably associated with changes in global atmospheric circulation patterns influenced by the melting of continental glaciers.[92] Shorter term and more recent fluctuations are more pertinent to predicting desert ecosystem response to cleanup operations since rainfall, the major variable in climatic change, is also the critical determinant of both desert vegetation community type and speed of recovery.

Studies of tree rings have documented 25- to 60-year periods of moist cool climates interspersed with dry warm climates in the southwestern deserts since the 15th century.[26,28] These studies show climatic anomalies to be of non-uniform geographic extent. For example, in the early to mid 1600's the Mojave and large portions of the Great Basin deserts experienced a climate warmer and drier than usual while most of the Sonoran and eastern Great Basin were normal, and the Chihuahuan was cooler and moister than usual.[27]

Recognition of the existence of these climatic fluctuations helps to interpret apparent historical vegetation changes and their causes. A number of authors have noted that the change from desert grassland to desert in the late 1800's coincided with a marked increase in man's use of grassland as cattle range, and have speculated a cause and effect relationship between overgrazing and the decrease in grass cover and increase in desert shrub vegetation.[14,32] Hastings and Turner[35] documented the influence of climatic change on this massive shift in regional vegetation and concluded that the new ecosystem was a response to the unique combination of climatic and cultural stress. Climatic change reduced soil moisture to a level below that required to establish new grass. Overgrazing contributed to the imbalance between infiltration and runoff through compaction of the soil and removal of existing grass.

1.3 MAN-MADE PERTURBATIONS

1.3.1 Fencing

Studies of evidence of vegetation change resulting from the exclusion of livestock from formerly heavily grazed land are abundant. Shreve recorded changes in Sonoran vegetation 22 years after exclusion[77] and again at 30 years.[81] He noted a general increase in plant population, that is, the number of species remained rather constant over the years but the total number of plants increased. The increase in the first 22 years was greatly exceeded in the next 8 years. No evidence of succession was found. Blydenstein[8] followed Shreve's work at 50 years. He compared the original enclosures with nearby control sites. In both the protected and unprotected sites the same species grew and in the same order of abundance. The most notable change was an overall increase in density of vegetation in the enclosed areas. Grasses and shrubs were beginning to replace *Larrea*.

Gardner,[30] reporting after 30 years of protection, found grass density about twice as great in the enclosed area. A more recent study of only 10 years' duration[14] noted no vegetation change. The authors speculated that soil compaction by grazing animals and/or erosion might account for the absence of effect.

Other authors[8,30] believe that it is soil erosion more than any other feature that is responsible for the many instances of slow recovery following livestock exclusion. When there has been little or no erosion and the original plant species have not been entirely removed, protection from grazing may lead to a rapid change in species composition and an increase in palatable (to cattle) species.[34]

To test the effect of rodents on range quality Brown[10] established plots that were grazed by cattle and rodents, by rodents only, and ungrazed by both cattle and rodents. He found that mesquite and *Opuntia* increased for all treatments but the poisonous shrub burroweed (*Haplopappus*) decreased under total exclusion. Morris[53] found that excluding rodents increased the density of native perennial grasses. A more recent study on 0.3 ha plots indicates that seed-eating rodents and ants are in direct competition for the available food supply. The exclusion of either taxon results in an increase in numbers and biomass of the other than results in a compensatory impact on plant population. When both fauna populations are excluded a 2- to 5-fold increase in plant density is noted.[13]

It has been speculated that the existence of a fence leads to increased animal utilization along the fence line, resulting in soil compaction and vegetation removal. Hansen[33] showed that cattle do not graze more closely and trample the vegetation near a fence than they did a hundred feet or more away.

Fences can act as protective as well as excluding landscape features. Elk in Washington have been restricted to the Cascade Mountains in historic times. However, they recently moved onto the ERDA Hanford research site which is fenced and not subjected to livestock grazing.[64]

1.3.2 Overgrazing

The effects of cattle grazing on desert grasslands have been extensively studied, but it is not always clear whether the observed effect, characteristically an increase in density in unpalatable shrubs and a decrease in perennial grass, were due directly to grazing or to associated factors, e.g., soil compaction by the grazing animal. Most of the literature deals with the role of livestock in promoting shrub invasion of grassland. Hastings and Turner[35] have summarized these studies and classified them to emphasize four ways in which domestic grazing animals have been thought to contribute to the spread of woody plants. The animals may act as disseminators of seeds, may reduce competition by selectively removing one species which inhibits growth of another, might serve as a fire suppression by removing the grass fuel from an area, or might reduce the moisture content of the upper layer of the soil by compaction.

Christian and Slatyer[18] have suggested a sequence of events which follows overgrazing and leads to irreversible (within human memory) change in vegetation. First, a depletion of perennial grass occurs, followed by wind erosion and a reduction of surface litter. The result is increased rainwater runoff, decreased water penetration, and higher soil temperatures. All of these factors create a more arid microclimate which inhibits re-establishment of the original vegetation.

The effect of grazing on lands that are now desert is less well studied than the effect on desert grasslands. Total primary productivity is low in desert areas and the grazing pressure on the most palatable species is high.* However, a characteristic of shrubs that persist in arid lands is adaptation to stress.[48] Rapid regrowth is a characteristic that enables shrubs to dominate desert areas. A number of shrubs are known to increase primary productivity and produce more new shoot growth when defoliated or closely cropped.[100] Overgrazing can also lead to a change in species composition and introduction of non-native species. Pechanec[56] reported overgrazing of sagebrush (Artemisia tridentata) in the Great Basin desert has led to the introduction of cheatgrass (Bromus tectorum) at the expense of native perennial grasses. If more species are removed than introduced, ecosystem stability will be lessened.

McKell[48] has noted that the worth of any shrub species can only be determined by assessing its relation to the major ecosystem and the extent to which user groups depend on it. Thus changes in species composition are not necessarily detrimental but must be evaluated in relation to land use. For example, the salt desert shrub community in the Great Basin desert moves toward dominance by blacksage (Artemisia nova) when protected from grazing, while intense winter grazing promotes an increase in shadscale (Atriplex confertifolia).[38] This is not an undesirable change for a rancher.[48]

1.3.3 Mechanical Disturbance

The effects on vegetation of compaction of non-agricultural desert soils by vehicles or animals, and by land alteration through blading or plowing, are generally specified by empirical observation rather than experimental measurement.

Almost any mechanical disturbance of the soil results in compaction since no soil is free from susceptibility to compaction. The magnitude of the compaction affects the rate of vegetation recovery. Compaction invariably results in long lasting visible effects. Jeep and tank tracks from desert training early in World War II are prominent in the Mojave, and Indian trails and wagon tracks of the last century can still be seen.[86] Although compaction slows recovery, natural processes eventually mitigate the effect. For example, although the streets of 19th century mining towns are still clearly visible, vegetation succession is occurring.

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*The definition of "most palatable" is obscure since relative shrub abundance and local environment may modify animal preferences. The phenomenon of "scarcity improves palatability" is well documented in range management.[48]

The primary effects of compaction are a greatly reduced soil pore space and increased bulk density which alter the relative amount of soil components present in a given volume of soil. These processes lead to a decrease in water infiltration, a decrease in water storage capacity and restricted air movement. This damage to soil structure severely impairs plant growth through decreased soil moisture and by limiting root penetration. A reduction in pore space from 55 to 34 percent has been shown to eliminate all plant growth.[29]

The secondary effects of compaction are changes in microclimate, since soil bulk density and thermal capacity are increased while diffusivity is almost unaffected. Soil temperature changes of -7°C have been recorded in compacted vehicle tracks (vegetation removal increased temperature by almost the same amount indicating a dynamic interaction between the effects of these processes).[45] Changes in microclimate can affect the germination of seeds.

Few data are available on recovery of compacted desert areas. Wells[99] showed possible succession in compacted areas. Gardner[30] and Buffington[14] speculated that compaction, and subsequent erosion were major factors in inhibiting regrowth in disturbed areas. Figures 1-2 and 1-3 show the persistence of compacted areas in the Great Basin and Mojave deserts.

Recovery of plowed and furrowed desert land is somewhat better documented, however. Rickard and Shields[65] measured the early stages of recovery on 2.5 ha plots denuded of vegetation by removing the surface 7-30 cm of soil with a bulldozer. After two years no shrubs had reappeared. Annuals were less abundant than on adjacent undisturbed areas. This was probably related to the removal of seeds with the surface dirt. Since annual growth is highly correlated with rainfall and seeds can lay dormant until climatic conditions are optimum for growth, the surface might contain the seeds from the previous three or four years' production. Bunchgrass (Oryzopsis) was present only when the roots of the predisturbance plant had not been completely removed. The authors concluded that mechanical soil and plant removal were more deleterious than plant destruction by atomic tests.

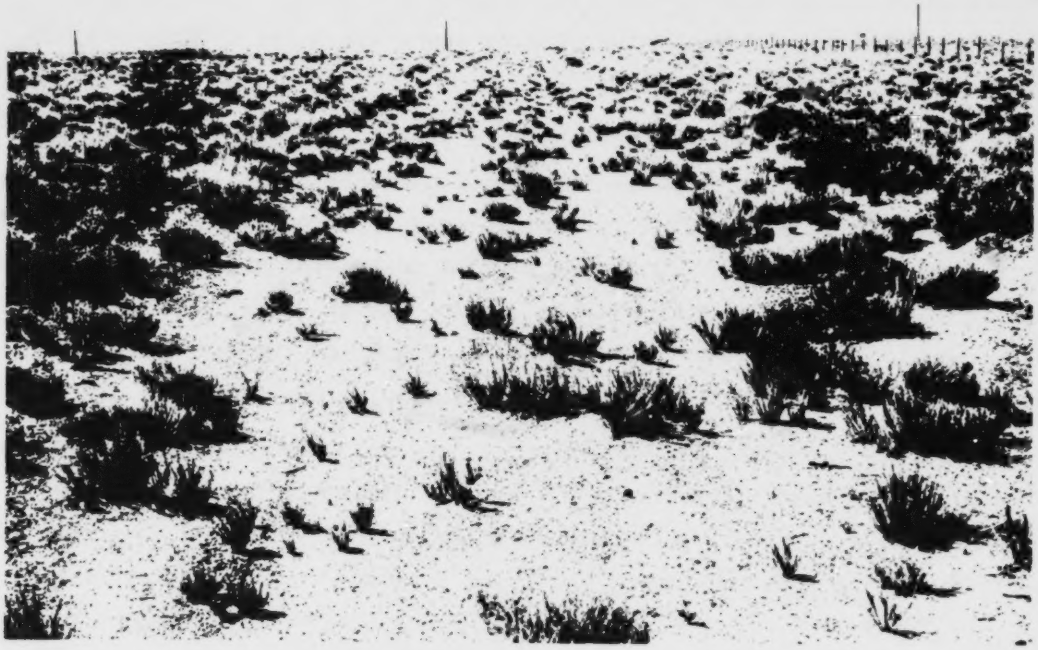

Figure 1-2. Great Basin Desert roadway unused for 15 years. The effects of compaction are evident. (Photo courtesy of UCLA.)

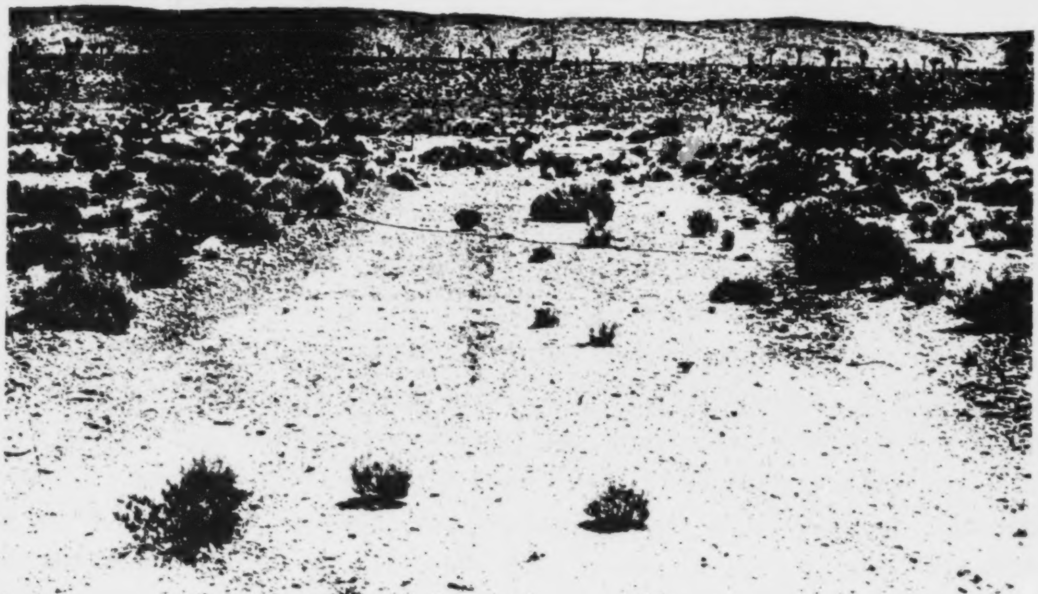

Figure 1-3. Mojave Desert roadway unused for 17 years. (Photo courtesy of UCLA.)

Abandoned farm land in desert areas generally follows the pattern of invasion by Russian Thistle (Salsola) during the first growing season, then the replacement of Salsola by grass, beginning in the second growing season, and finally the gradual reestablishment of the original brush vegetation.[59] Gardner[30] shows that thirty years of protection were not enough to erase the visible effects of plowing. Since soil is known to be compacted by improper tillage,[29] compaction is probably the effect noted. A disc harrow will compact soil at shallow depths (7-10 mm) while heavy machinery and trucks will drastically compact the upper 12-15 mm. Plowing often compacts soil at the plow depth.

Mechanical land alteration can also be beneficial to desert vegetation recovery. Brown and Everson[11] found that primary productivity on a ten year old furrow in the Sonoran desert was two and one half times greater than on the intra-furrow areas. The furrow impedes runoff, increases infiltration and reduces evaporation. Figure 1-4 shows this effect. These factors combine to increase available soil moisture and increase localized plant growth. This technique of land surface manipulation is used to assist the recovery of mine spoil banks where different surface topographies—deep chiseling, offset listering, gouging and basin construction—are routinely used.[90] It is also employed to contour water catchment basins to assist agricultural production in desert areas.[22] Occasionally a catchment basin is inadvertently created.[95] Figure 1-5 shows an unplanned catchment basin and indicates how plant growth is enhanced by the slight extra water. Figure 1-6 indicates that the increased water from roadway runoff can counteract the effects of compaction in desert soils.

1.3.4 Atomic Test Target Areas

Atomic test and associated construction activities at the Nevada Test Site have produced massive, and often-repeated, environmental perturbations. A typical surface or low altitude atmospheric detonation would destroy, by blast and thermal radiation, the vegetation in a circular area of 2-3 km^2. An underground detonation could cover 3-4 km^2 of desert with dirt ejected from the crater. In addition, large areas would be cleared of vegetation or leveled to accommodate diagnostic test equipment.

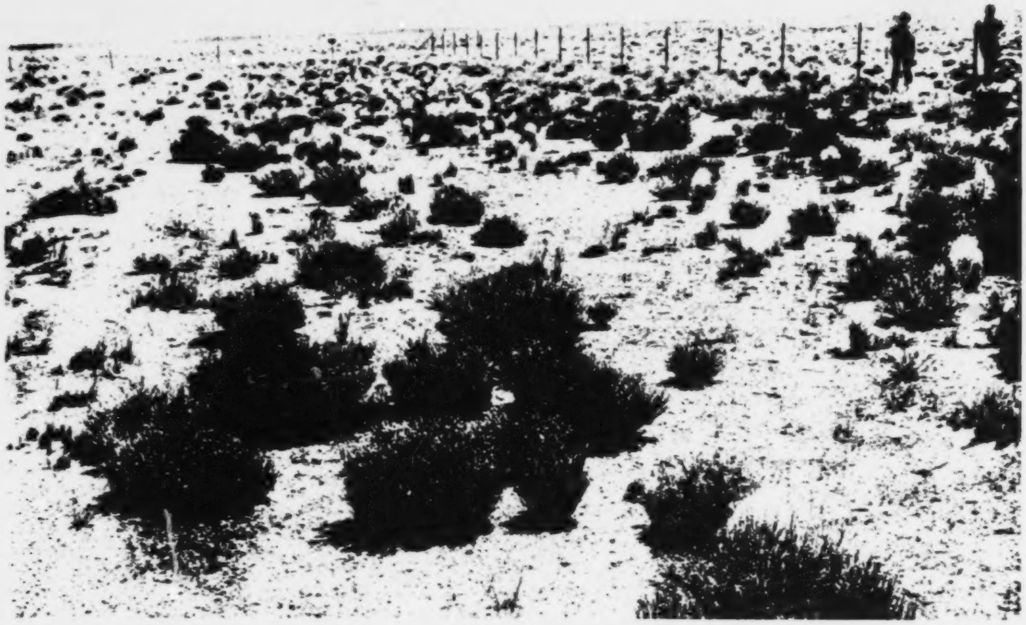

Figure 1-4. Great Basin Desert 11 years after blading and forming windrows. The fence at right encloses an area which has excluded grazing animals for 11 years. (Photo courtesy of UCLA.)

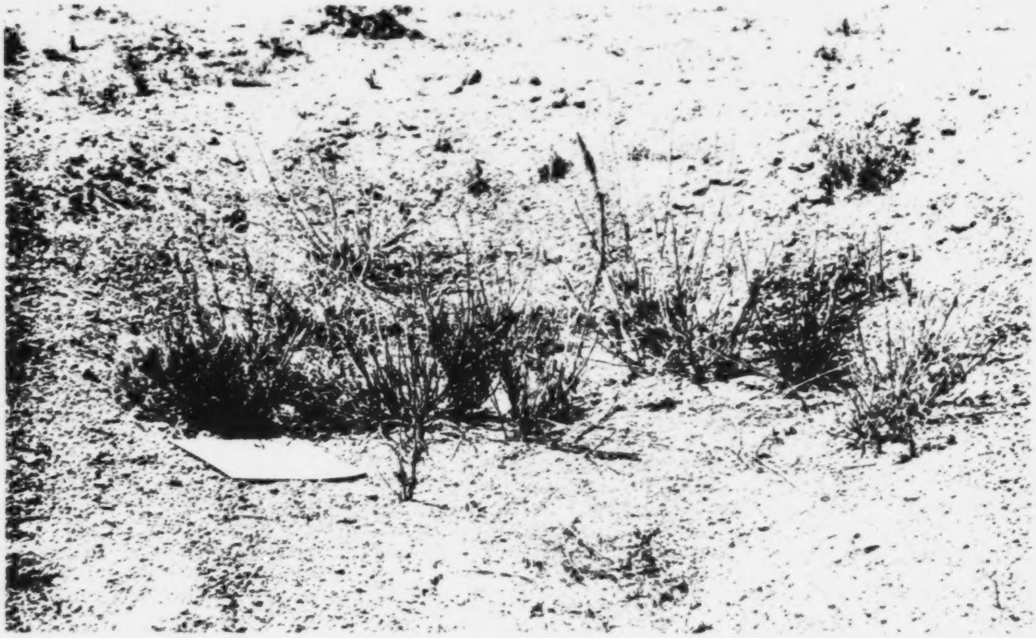

Figure 1-5. Mojave Desert. An unintended water catchment basin in a disturbed area. This basin concentrated the sparse moisture to allow plants growing within it to become better established than in the surrounding area. (Photo courtesy of UCLA.)

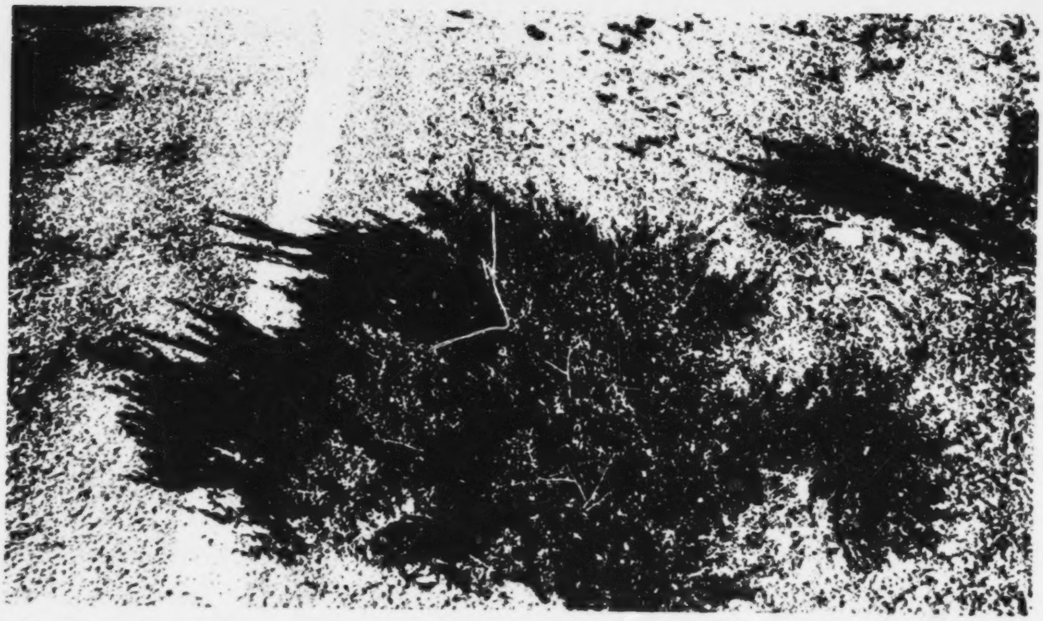

Figure 1-6. Mojave Desert. _Larrea_ growing in compacted area alongside asphalt roadway. Mojave species can reestablish themselves on disturbed areas if sufficient moisture, such as runoff from highway, is present. (Photo courtesy of UCLA.)

Three circular zones of damage have been identified around an atmospheric test burst point.[76] The first is an area about 1 km in diameter where all surface vegetation has been eliminated by blast or fire. The inner 0.2 to 0.5 km portion has had the seed containing layer of soil removed by blast winds. The second is an area extending about 1 km beyond the first zone where the perennial brush is broken but grass survives relatively unharmed. Finally, there is an area of shrub survival. This last area may respond to ionizing radiation effects in the following growing season.[62,63]

The immediate injury is attributable to mechanical and thermal effects;[74] however, recovery may be influenced by ionizing radiation. Radiation has been suggested as "stimulating" the growth of annuals,[3] or conversely as causing no observable effect.[74]

The pattern of revegetation is well documented[3,67,74,75,76] and the early stages proceed faster than recovery on bladed areas.[76] During the first year the inner portion of the barren zone is sparsely populated by annuals, evidently from seeds introduced naturally. In the outer portion of this zone the ground cover by annuals exceeds the total cover of nearby undisturbed areas, possibly because of the lack of competition with perennials for the available moisture. As the spring annuals die, the summer maturing Salsola dominates. Beyond the perimeter of denudation recovery occurs through the crown sprouting of the shrub species. In the second to fourth year the species composition of annuals changes. Grasses begin to dominate and the area resembles the grassland scars of natural burn areas. Saltbrush (Atriplex canescens), a characteristic species of roadsides, sandy washes and other disturbed areas, becomes abundant. The short term changes in vegetation are analogous to the succession observed by Wells[99] in a deserted townsite.[74] After twenty years, summer and winter annuals were found to be abundant, but there was virtually no recovery of the original perennial shrubs. The few shrubs which persisted were apparently crown sprouts.[67]

Little work has been done to document the vegetation recovery on crater ejecta. After nine years, Romney[67] reported that Salsola and summer and winter annuals were abundant except where the ejecta was "too thick," and speculated that the soil moisture infiltration rate on the loose dirt was too great to support vegetation.

1.3.5 Restoration

Attempts have been made to transplant seedlings and rooted cuttings of shrubs to speed the process of revegetation.[67,96] It was concluded that without supplemental irrigation transplanting perennial vegetation was a futile effort. Plant response and climatological behavior indicate that at least two and perhaps three consecutive years of favorable soil moisture are necessary for sage (Artemisia tridentata) seedling survival.[96] In one experiment where additional moisture was supplied to each transplanted plant, small animals destroyed all unprotected plants within a few weeks.[67] Construction of topographic features which concentrate available natural moisture appears to be the most practical method of speeding recovery.

1.4 EFFECTS OF CLEANUP PROCEDURES ON DESERTS

A number of cleanup techniques are available which vary in cost and efficiency. This section will list some of these techniques in the order specified by the EPA and will: (1) explain the technique; (2) discuss its effect on the local ecology; (3) indicate the closest analogy to vegetation succession and recovery from some natural or man-induced environmental perturbation; and (4) discuss the effect of increasing treatment area.

It is assumed that the methods used in construction industry and in farming to protect the surrounding areas from harm, especially from erosion or the deposition of eroded material, will be used. This will generally require the construction of silt dams and diversions.

(1-1) Chemical Stabilizers

The general purpose of chemical stabilizers is to bond the surface soil particles together to form a protective layer and isolate the subsoil from erosion due to wind or rain. The procedure often accompanies construction or road building activities. Chemical stabilizers could be used to immobilize a contaminant for a short (one to two years) period with a single application, for longer time periods with periodic application, or they could be used in conjunction with other cleanup techniques (e.g., scraping) to increase the effectiveness of the technique by bonding the contaminant to easily removed clumps, or to ameliorate the erosion effects after the cleanup, especially on steeply sloping areas. Vegetation is normally removed prior to treatment in construction activities; however, most of the chemicals, especially the polymer emulsions or resins, could be applied over vegetation if it was necessary to quickly immobilize the contamination.

Appendix A lists the chemical stabilizers preferred for desert areas. They include oil and latex polymers, polyacylamides (PPA), polyvinyl alcohol resin adhesives and other resins and polymers. These preferred treatments generally have an effective life of less than one year. Other chemical agents such as salt, sodium hydroxide, sodium carbonate, or iron chloride, also cause aggregation of soil particles. The ecological effect of these deflocculants is dependent on the soil ion exchange capacity and is highly area specific, thus will not be discussed here. Attempts to stabilize Pu contaminated soils at the Nevada Test Site with deflocculants have been reported.[95]

The soil bonding produced by the chemical stabilizers will reduce moisture infiltration and increase rain runoff. The chemical surface will also form a mechanical barrier to seed germination. Some types of treatment will result in absorption of solar energy and an increase in soil temperature. The increase may be great enough to inhibit seed germination as the chemical surface begins to degrade; however, this is unlikely since desert plants are tolerant to high surface temperatures.

The ecological effects result from changes in available soil moisture. Water runoff from the impervious surface will increase vegetation growth on areas immediately surrounding the treated area, much like vegetation growth is enhanced next to desert roads (Figure 1-7). Care must be taken that this runoff does not erode the soil from adjoining areas.

If vegetation is not removed prior to treatment, bunchgrass and perennial growth will continue during the next growing season, either by normal branch sprouting or, if the treatment kills the above-ground portion of the plant, by root crown sprouting. Since moisture will be able to enter the soil at the junction of the plant trunk and the earth, increased growth should occur since much of the available moisture will be channeled to the shrub, and the treatment will eliminate competition from nearby ephemerals while reducing soil moisture evaporation. Ephemeral vegetation and annual grasses will not appear until the surface begins to degrade. This might be the next growing season or the year following, depending on the time of year of treatment application. In

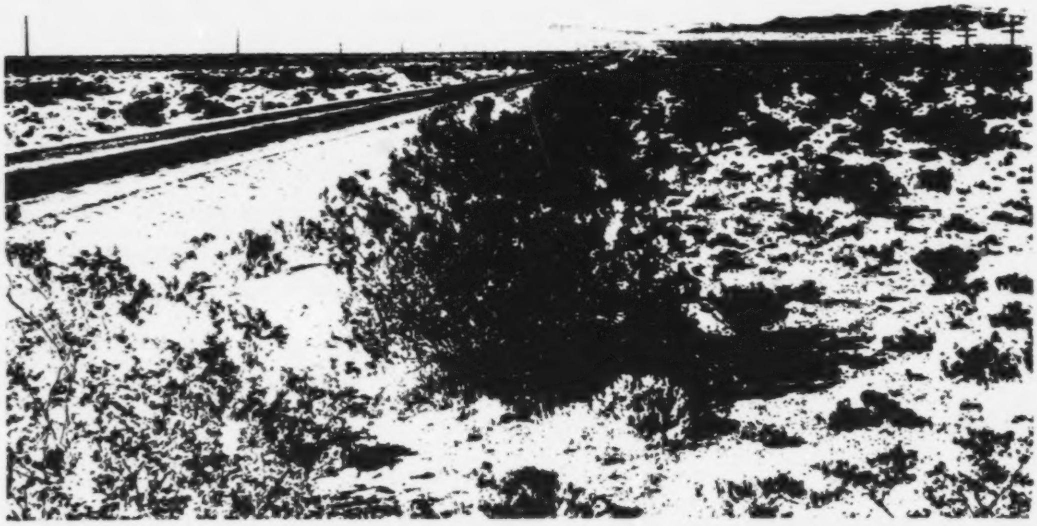

Figure 1-7. Mojave Desert. The effect of increased moisture from roadside cut on _Larrea_ growth. (Photo courtesy of UCLA.)

time, about a year depending on the chemical selected, cracks will develop in the surface. Moisture will concentrate in these cracks and allow germination of seeds resulting in localized vigorous growth which will accelerate the breakdown of the surface. Moisture concentration at the cracks may have a deleterious effect. If heavy rain occurs prior to the breakup of the crust and the establishment of annuals, erosion can begin under the crack area. The probable results would include faster breakup of the crust, gully erosion in the treatment area possibly exposing hardpan and a change in the drainage pattern.

Although the effective duration of most chemical treatments is about a year, clumps of stabilized soil, 5-20 cm in diameter will persist for longer periods of time. Recovery of the area, compared to surrounding areas, depends on recovery of the ephemerals and grasses, which in turn is related to the breakdown of the clumps of stabilized material. This should occur within three to five years after treatment.

If the vegetation is removed prior to treatment, recovery of bunchgrass and perennial shrubs will proceed from the underground portion of the perennial vegetation as the surface degrades. The area will recover full biological productivity within three to five years except where the soil has been compacted by the brush removal or chemical application equipment. The treatment area will be visible until the perennial vegetation achieves full stature—about twenty to thirty years. The compaction effects of the heavy equipment will be visible for a longer time.

If the chemical layer is not toxic to animals it will not inhibit the burrowing activities of rodents; moreover, the burrowing might bring to the surface the material the chemicals were intended to bind. If the area is relatively small, i.e., 1 ha, the rodents will probably not be displaced but will forage for food outside the treatment zone. If the treated area is larger than the animals' normal forage range, about 50 m for pocket mice to 100 m for Kangaroo Rats,[2,25] a migration to other areas can be expected. The effect of this migration on the surrounding area would be difficult, if not impossible, to measure. It is generally hypothesized that desert rodent species diversity is directly related to precipitation, through the relationship between precipitation and primary production.[12] It is doubtful whether the surrounding habitat could support the additional population. The weaker members would die off. As vegetation reappears in the treated areas, animals will return. Desert rodents of different species harvest different sizes of seeds and forage in different microhabitats.[12] Since there is little evidence of sequential desert vegetation succession, there should be no change in animal species diversity as the treated area is recolonized. If vegetation is removed however, changes in rodent diversity might be expected until the area is well along toward full recovery. This point is discussed later.

Progressively greater care must be exercised for the larger treatment areas to handle rain runoff. If the largest areas are treated on a routine basis over a number of years, ground water recharge will be inhibited. The effects must be estimated for each individual case.

(1-2) Clear Cutting Vegetation

Vegetative cover can intercept part of the deposit of an airborne contaminant, and removing vegetation might remove a considerable portion of the contaminating material while also inhibiting transfer and possible concentrations through food chains.

A number of methods are available for vegetation removal. Hand hoeing and shovel cutting would be applicable for the smallest area, or for steep hillsides; however, mechanical techniques would be required for larger areas. These mechanical techniques include cabling and anchor chaining and are common in range improvement programs.[31]

In cabling, a 45 to 60 m long 3.75 cable is dragged between two tractors traveling on parallel courses. The cable breaks off or uproots brush. Cabling can be used where the brush breaks easily and is not willowy. The technique results in little effect on perennial bunchgrass and usually leaves the A soil horizon and humus at the base of the brush intact, an important consideration for revegetation.

Anchor chaining consists of dragging a heavy (up to 50 kg per link) chain through the vegetation to break or uproot plants. The general procedure is much like cabling but the ground is more disturbed, the underbush humus is usually scattered, and soil stabilizing algae clumps are broken. Chaining will clear brush up to the size of small trees. The spacing of the parallel tractors, and thus the spacing of the compacted areas, is dependent upon density of vegetation, weight and length of chain, size of tractor, bite of tractor tread, and ground slope.

The effects of hand removal would be relatively benign. Most perennial vegetation would resprout in the following growing season. The seeds of annual vegetation would not be disturbed.

Soil compaction by the mechanical equipment would be the major deleterious effect of mechanical removal. Broken perennials would resprout from underground plant parts. The summer annual forb Russian Thistle (Salsola) would invade the area, especially the chained area, the following summer since Salsola only germinates where the soil surface has been scarified.[94] Salsola roots cannot penetrate compacted soil and would thus be restricted to areas between the tractor paths. Winter annual grasses (Bromus) and the Salsola might delay revegetation of the areas by native species by their effective use of available soil moisture. Salsola can thrive at below normal desert rainfall levels;[93] with normal rain annual grasses, followed by native ephemerals, would become established. Recovery would be more rapid than if the seed containing layer of soil were removed.

Erosion by wind would be a major problem until the annual vegetation or algal mat was reestablished, or until natural soil compaction by rainfall occurred. This problem is largely non-ecological however, since the main effect of eolian erosion is the removal of the A horizon of soil, which virtually does not exist in desert soils. The major danger would be due to winds spreading the contaminant beyond the treatment area. Dust from the area should produce no lasting effects on the surrounding vegetation; however, 10 km^2 denuded of vegetation could produce a highly visible and undesirable dust cloud.

Vegetation removal is likely to affect microclimate. The low-level wind speed profile will be changed due to changes in aerodynamic roughness.[44] This change will lead to increased evaporation, increased soil temperature and decreased humidity. These will affect both the revegetation of the treatment area and the plant growth outside the area.[23]

Temporary food reduction would be the major effect on animals. This effect, like chemical stabilization, will increase with increasing treatment area.

(1-3) Stumping and Grubbing

This procedure would produce a drastic perturbation on the desert area, and would probably only be used in conjunction with another cleanup technique if it were desired to restrict the regrowth of perennial vegetation.

Desert plants have extensive root systems. The ratio of root to top of plant varies from 0.5 to more than 4, and the majority of plants have a greater biomass below ground than above.[96] The structural roots systems range from massive tap roots and secondary root systems to filamentous systems. The depth of roots somewhat depends on the depth of hardpan or caliche deposits, but unless these deposits are shallow most roots will extend to a depth of 1 m. Creosote bush roots are known to extend 2 m.

Roots can be removed by hand. However, mechanical methods would probably be employed. A backhoe or crawler type tractor with a "hula dozer" blade can be used to remove root systems.

The major ecological problems are again associated with soil compaction by the equipment. However, the earth disturbed while removing the roots could cover the annual-seed containing layer of soil and slow the initial stages of natural recovery to two or five years. If caliche were brought to the surface, it could form a pavement-like crust that might further restrict plant growth.

The treatment will destroy rodent burrows and probably result in immediate death to a great portion of the local rodent population. Long term effects will be related to the destruction of the food supply. Beatly[6] has shown that in Southern Nevada the dominance order of some heteromyids changes following brush removal or ground clearing, i.e., replacement of Dipodomys microps by the smaller D. merriami. She suggested an animal vulnerability to elimination by predators of the larger species where there are few shrubs in the environment.

The environmental effects will scale with the size of the area: the greater area disturbed, the greater the effect.

Areas of the Great Basin and Chihuahuan deserts which receive more than 250 mm of annual precipitation could be reseeded with grass to result in desert grassland; however, the prognosis for recovery within a human generation in other desert areas is poor.

(1-4) Scraping and Grading

The upper layer of soil to about 5 cm depth along with the contaminant would be removed by road grader, land scraper, bulldozer or vacuum cleaner. This is a drastic perturbation on the desert environment since it removes the small amount of A horizon soil that exists under brush and also removes the seed containing layer of soil. Wind and water erosion potential would be maximized and a further deleterious effect would be soil compaction by the earthmoving equipment.

Under most circumstances the above ground portions of perennial vegetation would be removed with the soil layer. However, it has been suggested that leaving 200-800 shrubs per ha would speed recovery by providing seed for natural re-seeding.[95] Desert perennial plant density normally ranges from 400 to 3000 plants per ha.[16] Thus, between one half and one quarter of the perennial shrubs would remain if this suggestion is followed.

If both soil and plants are removed, some resprouting of shrubs could be expected; however, the treatment would remove all traces of bunch grass. The revegetation sequence of Salsola, annual grasses, native annuals, and the gradual reintroduction of perennial species as outlined in Section III would occur. Recovery would be slow. Animal recovery would be expected to follow plant recovery.

If some shrubs are allowed to remain, the effect on the animals would not be as drastic, since the brush would supply animal cover and food and provide seed for continued revegetation. The humus under the plant could contain seeds of ephemerals and would partially preserve the fertile shrub site in which seedlings can become established.

In addition to the potential off-site problems that are associated with erosion, some provision must be made either to remove or to store the contaminated soil. This normally will require a tract of land in addition to the treatment area.

Figures 1-8 through 1-13 show the recovery that might be expected eleven and seventeen years after scraping a desert area.

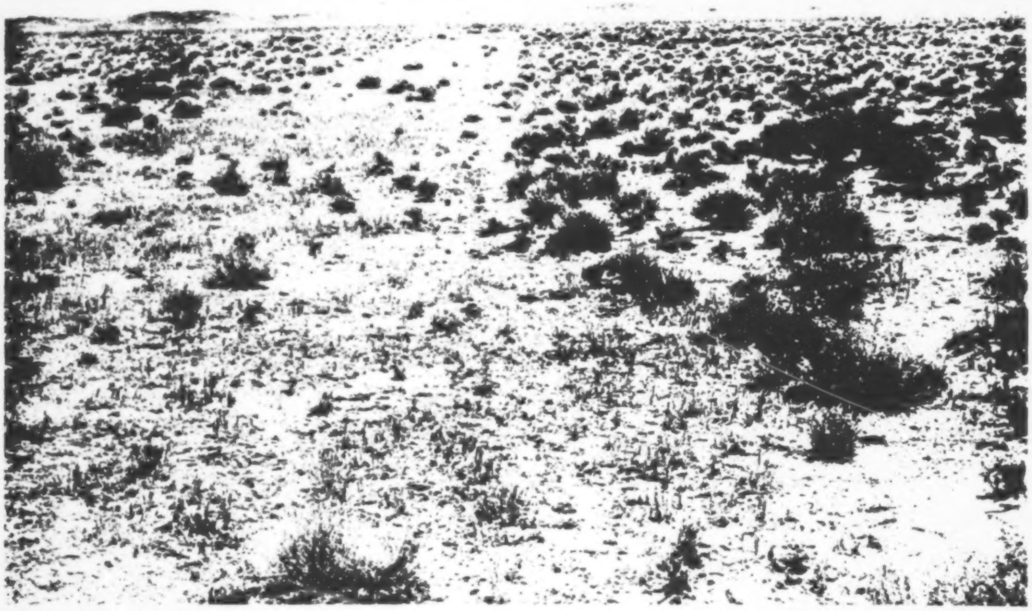

Figure 1-8. Great Basin Desert. A 2 ha rectangular plot 11 years after blading. Many grasses are present. The poisonous shrub Halogeton can be seen in the lower part of the photograph. (Photo courtesy of UCLA.)

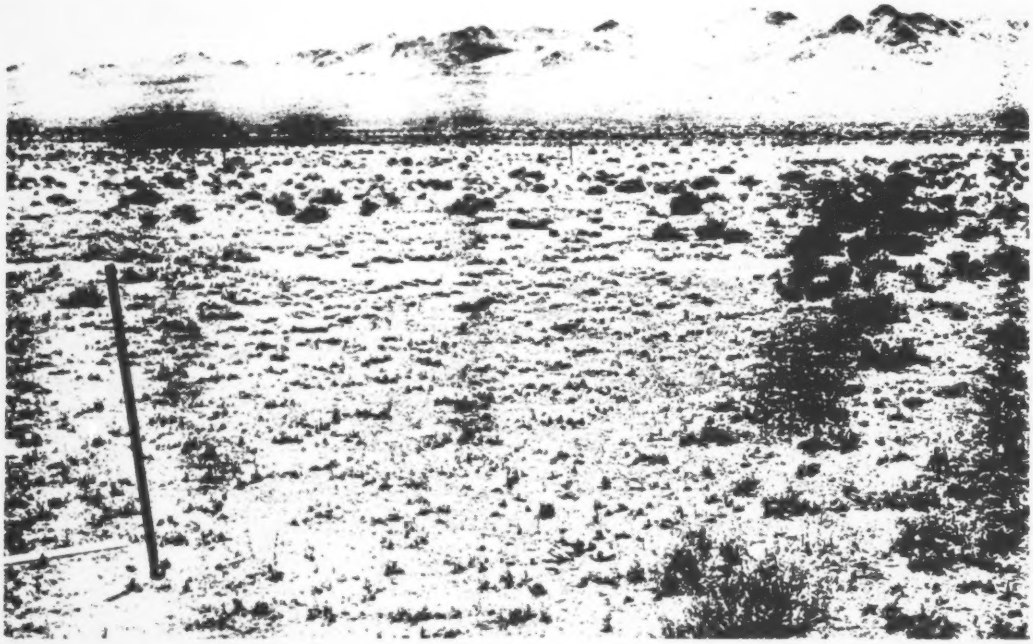

Figure 1-9. Great Basin Desert 11 years after blading. (Photo courtesy of UCLA.)

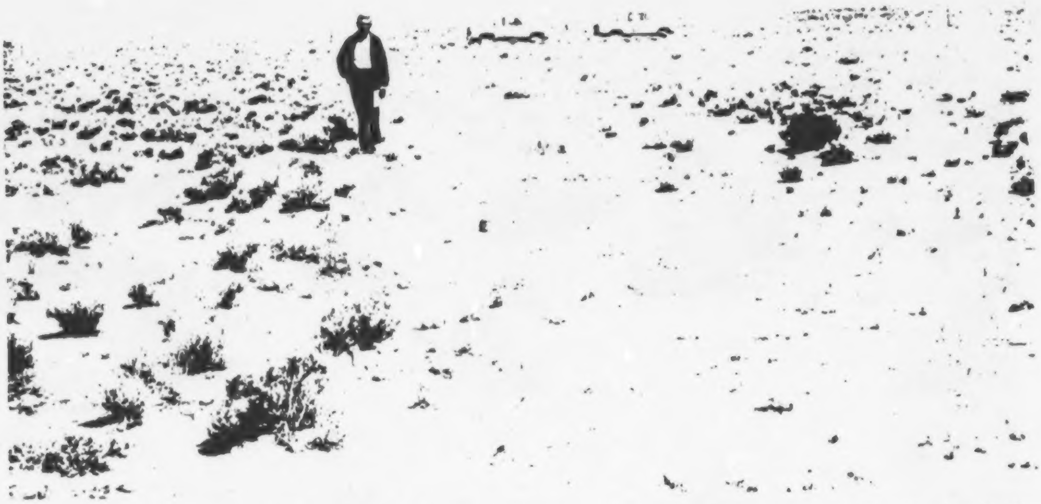

Figure 1-10. Great Basin Desert. Demarcation line between land bladed 11 years ago (right) and non-bladed land (left). The bare areas may relate to depth of blading. (Photo courtesy of UCLA.)

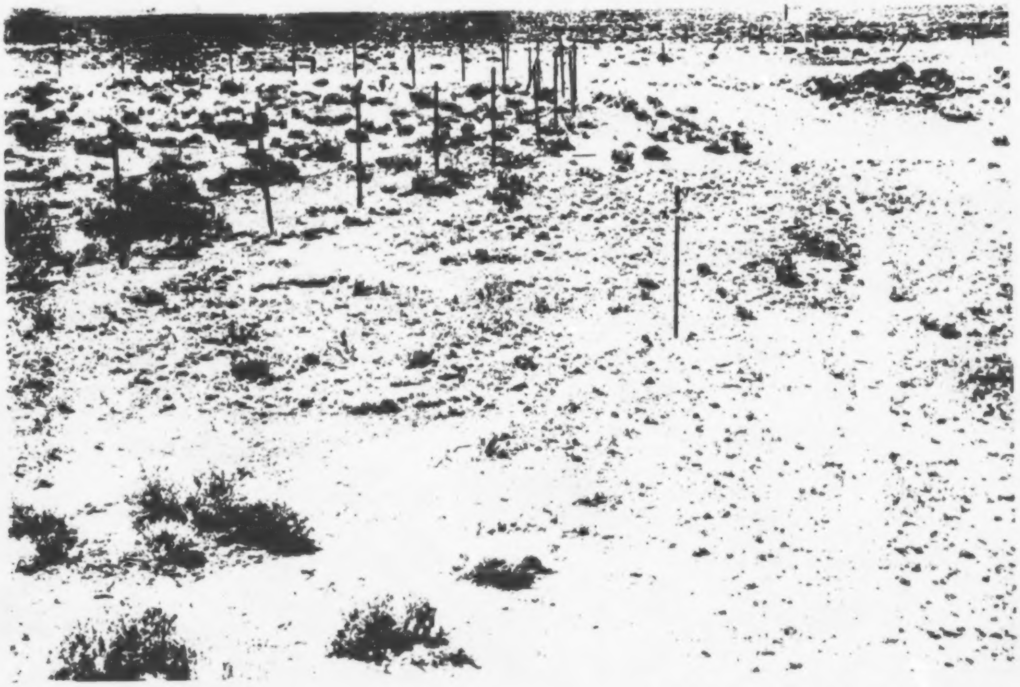

Figure 1-11. Great Basin Desert. Area in foreground and right was bladed 11 years prior to the photograph. (Photo courtesy of UCLA.)

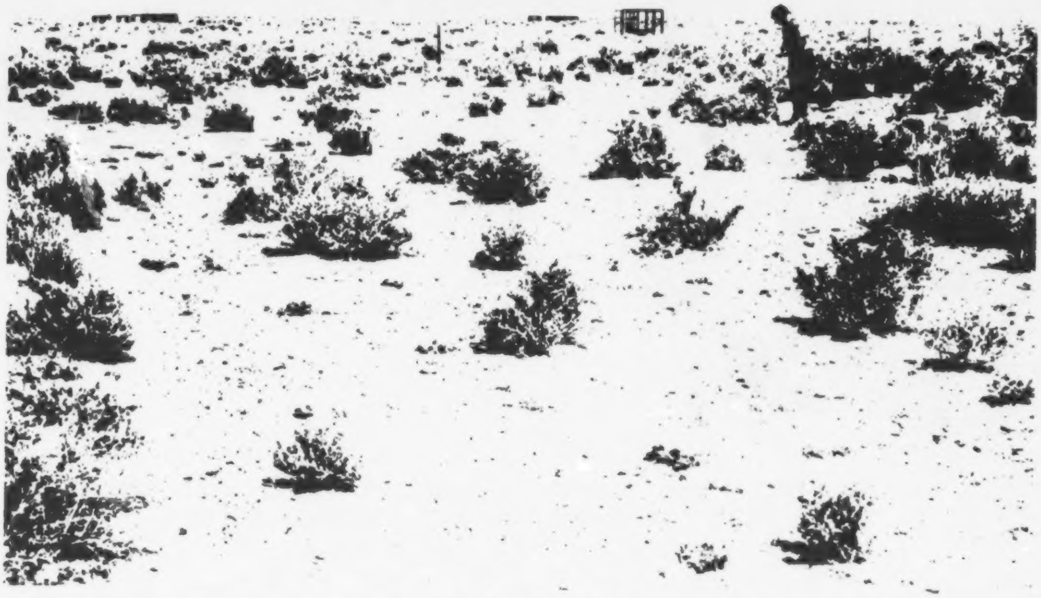

Figure 1-12. Great Basin Desert 17 years after application of water to reduce dust followed by blading. (Photo courtesy of UCLA.)

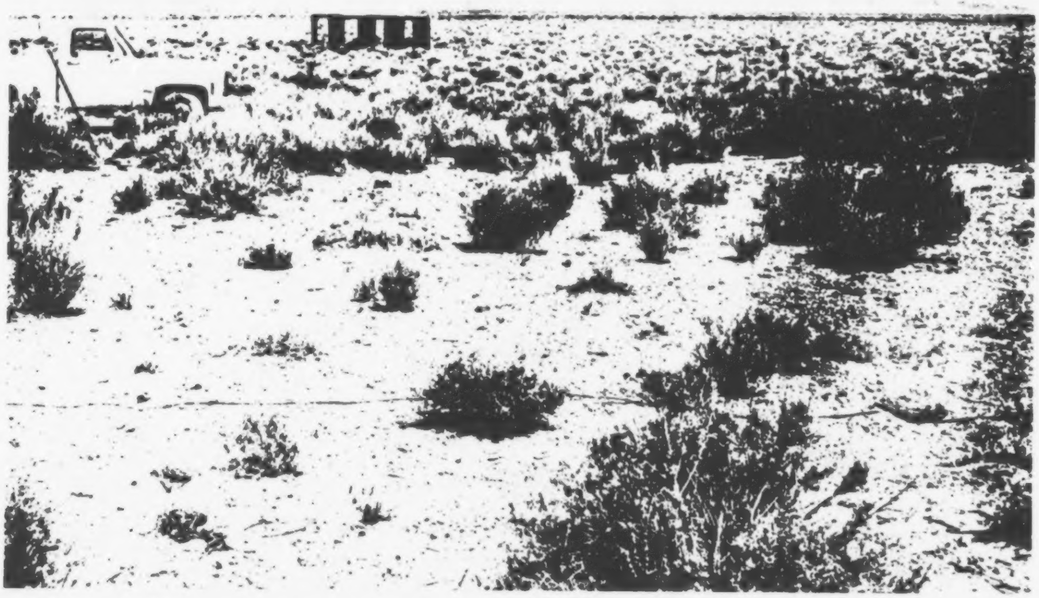

Figure 1-13. Great Basin Desert recovery 17 years after blading. The cover in the foreground bladed area is about 25% of the undisturbed area. It is unknown if the plant grew from seeds or crown shoots. (Photo courtesy of UCLA.)

(1-5) Shallow Plowing

It is assumed this technique plows the soil to a maximum depth of 10 cm between the perennial shrubs. It disturbs both annuals and bunch grasses but not most of the shrubs.

The ecological impact would be less than for surface scraping. The shrubs would provide food and cover for animals and a seed reservoir for new growth. Little humus would be lost and the seed-containing layers of soil would not be removed. Scarification of the soil would enhance Salsola growth for the first two or three years. This growth would have little effect on germination of annuals since Salsola is a summer germinating plant while other annual forbs and grasses are spring and fall germinating. The potential for wind erosion would be increased until ground cover by annuals is established. The potential for water erosion could either be increased or decreased depending on the plowing technique.

The visual effect, e.g., low furrows, would be visible for many years. There would be little effect on animal food supply or population density.

(1-6) Deep Plowing

Plows capable of plowing as deep as 100 cm are available. This technique would result in a complete destruction of the local ecosystem. Succession would start from bare ground. The relatively thin soil under perennial plant clumps would be destroyed and most of the seed-containing soil would be turned under. Animal life would be displaced or destroyed.

Larger areas would undergo initial stages of recovery more slowly than smaller areas unless some form of revegetation were attempted.

Figure 1-14 shows the recovery to be expected from deep plowing.

(1-7) Soil Cover Less than 25 cm

The purpose of this technique would be to bury and immobilize the contaminant. It is a relatively drastic treatment. It would be difficult, if not impossible, to accomplish without affecting the hydrological drainage system outside the treatment area. As new drainage patterns are established and old ones abandoned, the vegetation of individual areas would change, although the overall effect on the region might remain unchanged.

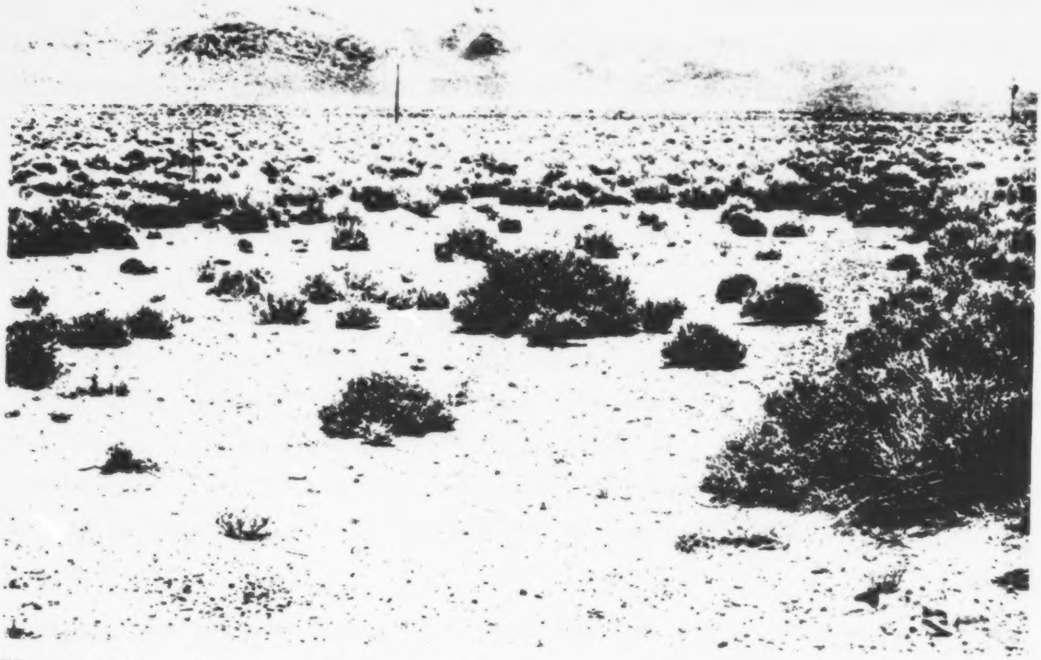

Figure 1-14. Great Basin Desert 17 years after plowing. The area in the foreground was plowed to a depth of about 30 cm. Cover on plowed area is about 25% of that of the undisturbed area. (Photo courtesy of UCLA.)

If the soil were placed without extensive compaction, some shrubs would survive since a few desert shrubs are evidently adapted to periodic silting by erosional processes. Few data are available on the plants that could survive; it is assumed those found in washes or arroyos such as Hymenoclea or Thamnosma could withstand limited soil cover and grow. However, it is epxected that most shrubs and all bunch grasses and annuals would be incapable of growth or germination.

Recovery would be essentially the same as starting from bare ground. Unless some type of seeding program were instituted, the growth of annuals on the larger-sized treatment areas would not occur until winds deposited seed.

Compaction density of the fill will be an important variable for regulating the time of the initial stages of recovery. If no compaction occurs the situation could approximate that around nuclear craters where the water infiltration rate is so great that germination cannot occur. Alternatively, compacting to a density greater than the original soil would also inhibit plant growth.

(1-8) Soil Cover 25 to 100 cm

This technique would result in the complete loss of the treatment area ecosystem as well as off-site changes induced by changing surface drainage patterns. Recovery of the treatment area would be from bare ground.

(2-1) Remove Plow Layer

This cleanup procedure increases the severity of method 1-4, Surface Scraping and Grading, by removing slightly more soil. When the top 10 cm of soil are removed all annual seed, humus, bunch grass and the meristematic tissue of most shrubs would also be removed. A few shrubs would resprout from the roots, but most would not. Recovery would essentially start with bare earth. In some desert locations extensive deposits of caliche are found at plow depth. If these are exposed the existing slow rate of recovery would be retarded.

(2-2 Remove Shallow Root Zone

This method would remove the top 40 cm of soil from the contaminated area. This technique would remove both the A and B soil horizons and expose the calcarous C horizon. The result would be complete destruction of the local ecosystem. Recovery would begin from bare ground.

In any of the surface alteration procedures, i.e., scraping, grubbing, plowing, or soil removal, loss of vegetation and the exposure of the soil to winds and rain will lead to erosion problems. The magnitude of these problems is discussed in Chapter 2, Prairies, and Chapter 8, Agriculture.

(2-3) Scrape and Grade, Mechanically Stabilize

This technique would use mechanical methods to provide stability to the freshly scraped soil to retard or prevent soil erosion. The method would be expected to lessen the impact due to erosional deposition on surrounding areas. However, none of the possible mechanical stabilization processes would appreciably speed natural recovery, and some of the possible processes would slow it.

Two categories of mechanical stabilization are considered here: compaction and manufactured materials such as nettings, meshes, or plastic films.

Soil can be mechanically compacted by bulldozer, rollers, or vibratory processes to a density that rejects water. The degree of compaction is largely a function of the amount of clay in the soil. The compacted soil can resist wind and water erosion for decades. Eventually natural processes allow ephemerals and grasses to become established. This vegetation helps loosen the soil so that natural revegetation processes can occur. If the soil has a very high clay content, as is the case for dry lake playas, revegetation might require centuries.

Although the surrounding area is protected from material eroded from the treatment area, the increased water runoff during a rain, unless controlled, would cause severe erosion problems on the adjacent land.

Manufactured material, like netting, placed over the scraped area would provide protection against water erosion, and limited protection to winds. The ecological effect would be substantially the same as if the mechanical stabilization were not done.

Plastic film could also provide a protective layer. If exposed to air the film would last 3 months to 2 years, depending on the composition of the film. Films covered by earth could last much longer; however, winds could quickly remove the cover. As the film degraded, normal restoration would occur.

(2-4) Remove Plow Layer, Mechanically Stabilize

A severe environmental disruption. The effect would be substantially the same as described above, expect the compaction of the clay C horizon found in many desert areas would form a long lasting barrier to recovery.

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

A severe environmental disruption. The effect would be substantially the same as described above.

(2-6) Scrape and Grade, Chemically Stabilize

This composite method, like the mechanically stabilized methods described above, would depend on soil removal to reduce contamination and a stabilizer* to both fix any remaining contaminant in place and to retard soil erosion. Any cleanup procedure that removes soil results in loss of the local desert ecosystem. The chemical (and mechanical) stabilizers protect the surrounding areas from losses due to erosion, but at the cost of slower recovery at the treatment area.

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*Appendix A lists the stabilizers. It is assumed here that one of the preferred stabilizers of Appendix A, as listed in Treatment 1-1 above, would be used.

The effects of scraping and grading were described in treatment 1-4 above. The addition of a chemical stabilizer would retard the initial stages of recovery until the stabilized crust was degraded. Shallow scraping will leave some perennial brush roots capable of resprouting, but forbs and grasses cannot germinate until the surface develops cracks which allow wind borne seeds to be deposited.

Since the stabilizer will prohibit water infiltration, provision must be made for mitigating the effects of runoff on the surrounding areas.

(2-7) Remove Plow Layer, Chemically Stabilize

Soil removal is a drastic environmental perturbation. The chemical stabilizer would retard the initial stages of recovery one to two years.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

The ecological effects are substantially the same as described above.

(3-1) Barriers to Exclude People

This treatment would depend on isolating the contaminated area from human contact. This will only be effective if the contaminant cannot enter the food web leading to man. The most probable barrier would be chain link fencing six to ten feet high. Such fencing can be expected to be useful for 25 to 30 years.

As long as provision is made for animal passage the barrier would have no effect on local ecology. Some cultural, e.g., archaelogical, features would also be protected by the barrier.

(3-2) Exclude Large Animals

Fences can be designed to inhibit animal movement. If cattle and large game animals are excluded from the contaminated area, one direct link in man's food web will be blocked.

Studies, described in preceding sections, have shown that cattle exclusion does not result in changes in vegetation species composition (at least over the

50-year measurement period), but that the number of individual plants, and thus the total productivity of the fenced area, increases markedly. An increase in primary productivity should lead to an increase in the number of small herbivores.

A fence might produce deleterious effects on large animals in two ways. First, it might exclude animals from natural water places. Second, it could impede a natural migration path. Lack of a secondary watering place would prove fatal. If other migration routes were available they would probably be used.

(3-3) Exclude Large and Small Animals

This procedure would inhibit the transfer of the contaminant through the food web. Barriers can be made to stop both the immigration and emigration of animals. It is assumed that large grazing animals, e.g., cattle, burros, antelope, deer, would be removed from the contaminated area. It would be possible to exclude birds from the smallest treatment zone (0.01 km^2) and it might be worth the effort if a particular microenvironment, e.g., one containing an endangered plant species, were to be preserved, but it would be impractical to exclude birds from larger areas. The actual isolation of the food web leading to man would require analysis of the local conditions and extent of man's use of local birds.

It might also be possible to remove small animals from areas smaller than about 1 km^2, but it is doubtful if attempts at either direct physical removal or removal by poisoning from larger areas would be effective.

If small seed-eating animals are removed it is postulated that a compensatory increase in seed eating insect populations will result in about the same utilization of the local plant resource.[13]

The effect of inhibiting small animal movement, rather than removal, is less clear and is undoubtedly related to the size of the area fenced. The interaction between plants, herbivores, and carnivores plays an important role in the local ecology. Plants could exist in very small enclosed spaces. Herbivores and carnivores require areas at least as large as their foraging range. Only the largest area, 10 km^2, may be large enough to support a population of carnivores in a closed system, based on ecologies existing on small isolated desert areas such as islands. It is not clear what the effect of smaller fenced areas would be. One study, using the vole Microtus, found that 0.8 ha fenced plots evidently destroyed the species' natural population control and regulatory mechanism. The fenced population expanded until it was about three times as large as control populations on adjacent sites. The result was overgrazing and destruction of the habitat, followed by starvation induced population decline.[43] No evidence of this phenomenon was observed on 8 ha plots in the Mojave desert[25,96] although herbivore population densities within the fenced areas differed from adjacent control densities in non-uniform ways.

As long as the vegetation is not degraded or destroyed, recolonization of the areas after removal of the fence would be relatively rapid. The abundance of small mammals respond quickly to periods of good vegetation growth. They have been reported to increase their densities at least five-fold within one breeding season.[24] French[25] has shown that desert rodents in the Mojave Desert disperse to great distances both as young animals and as adults during the non-breeding season.

Continued maintenance of isolated animal populations could affect the gene composition of the group. The smallest groups would be affected the most.

(4-1) Asphalt Hard Surface Stabilization

In this procedure asphalt or hot rapid cure road oil would be applied over the contamination to immobilize it. The vegetation would be removed prior to the asphalt treatment, but might remain for the road oil application.

The technique limits wind erosion; however, drainage and runoff of rainwater to adjoining areas would be a problem.

In the asphalt treatment the ecology of the treatment area would be destroyed. Some perennial plants would survive the road oil, but the area would be virtually useless to support annual vegetation or animals. It is expected that vegetation at the edge of the area would exhibit enhanced growth due to additional available moisture.

The asphalt and road oil treatments will affect local microclimate. Decreased surface roughness will result in changes in the wind profile and will decrease humidity. The local heat balance will be changed since an essentially spongy surface of low heat conductivity will be turned into an impermeable layer with high capacity for absorbing and conducting heat. This will raise local air temperatures. In calm weather conditions an inversion in the nocturnal atmosphere can be created that will affect surface wind flow and temperatures over a relatively large area. This "heat island" effect has been noted in areas as small as 0.1 km^2.[44] The lowered humidity and increased temperature will deleteriously affect the small annuals and ephemerals more than the perennials.

No recovery can begin until the surface begins to degrade. This should occur in about three to five years for the road oil and five to ten years for asphalt. (However, asphalt can be placed over a compacted base at a thickness which will survive fifty years or more.)

As cracks develop in the surface both moisture and wind borne seeds will be concentrated. The resulting growth will help break up the surface. As more of the surface degrades, annuals, then perennial plants, will become established. The largest area considered for this treatment, 0.1 km^2 should not reduce infiltration and recharge to the extent that ground water would be affected. However, the water table under large paved desert areas, such as airports, has been shown to move closer to the surface in response to reduced surface evaporation. Figures 1-15 and 1-16 show recovery from road oil stabilization.

(4-2) Concrete Hard Surface Stabilization

This treatment is outside the scope of work.

(5-0) Application of Sewage Sludge

This treatment is outside the scope of work.

(6-1) High Pressure Washing

This treatment is outside the scope of work.

(6-2) Flooding

This treatment is outside the scope of work.

(7-0) Soil Amendments Added

This treatment is outside the scope of work.

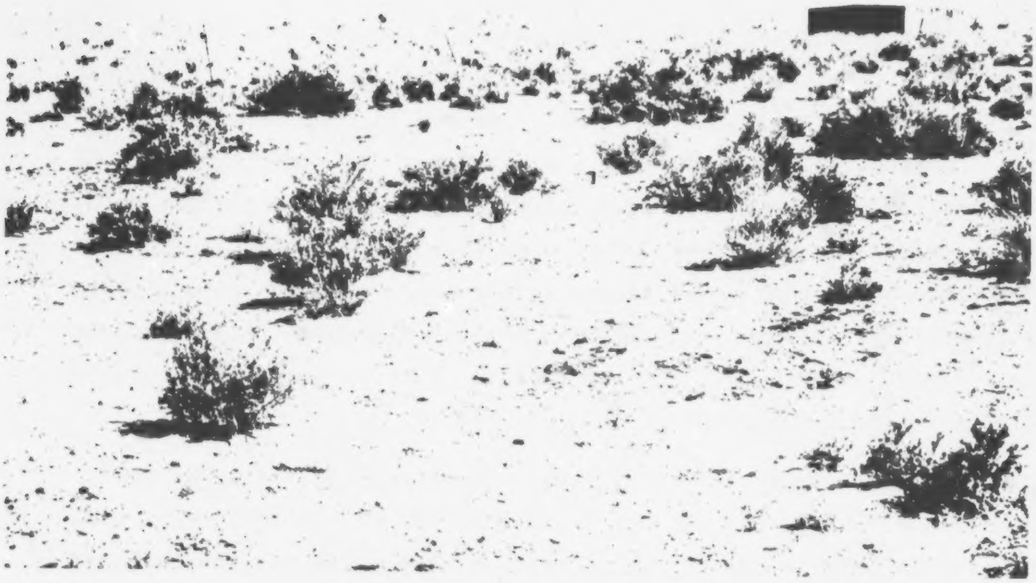

Figure 1-15. Great Basin Desert. Foreground first treated with hot, rapid-cure road oil stabilizer, then scraped. Photo 17 years after disturbance. (Photo courtesy of UCLA.)

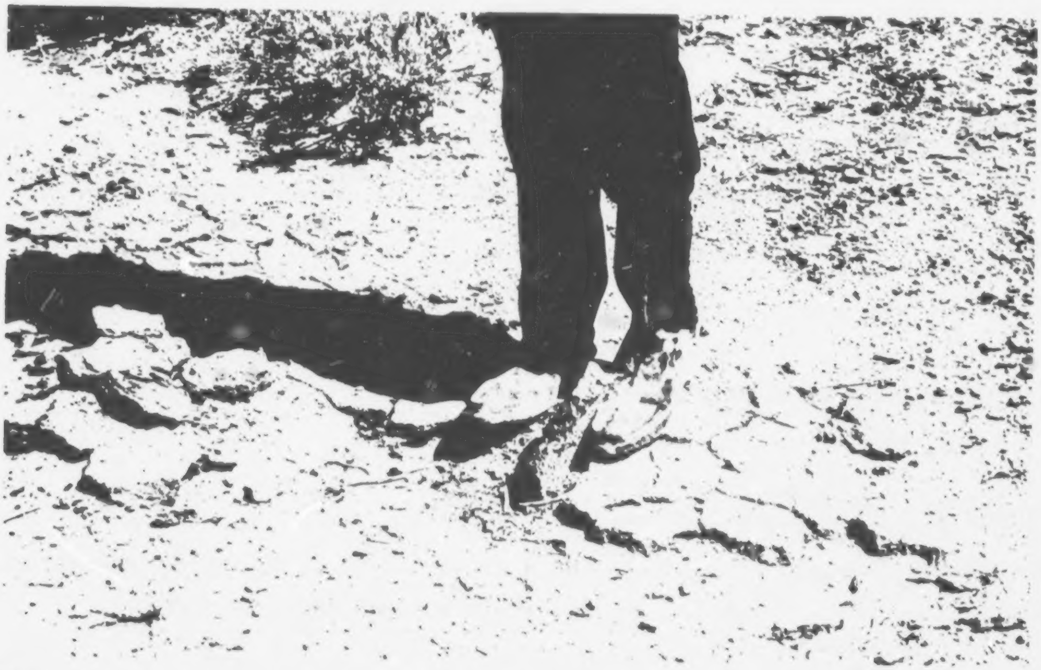

Figure 1-16. Soil 17 years after application of a hot rapid-cure road oil stabilizer. The soil pieces vary from 1 to 5 cm thick. Vegetation is growing in the area. (Photo courtesy of UCLA.)

1.5 RECOVERY FOLLOWING CLEANUP

Earlier in this chapter it was noted that the concept of a single stable climax vegetation in each desert type was not valid. A number of different stable ecosystems may be possible depending largely on long term climatic factors.[35] Further, existing ecosystems are dynamic and changing with time. Thus, recovery is best defined in terms relative to surrounding areas rather than to some standard climax ecosystem, or to some measured pre-treatment condition. It has also been shown that there are no irreversible changes; given enough time the desert will adjust to any insult. Treatments which lead to massive erosion and land form change will be permanently altered visibly although the change will not affect the equilibrium ecosystem.

The endpoint for natural secondary succession and unassisted recovery following application of one of the cleanup techniques can be specified in a number of ways depending largely on the effort undertaken to measure the completeness of recovery.

These endpoints include:

(1) No measured difference, other than normal variance based on measurement technique and ecological variability, in selected ecosystem components between the treatment area and adjoining undisturbed areas.

(2) No visible difference between treated and untreated areas apparent to a desert ecologist, without benefit of field measurements.

(3) No visible difference to the layman.

In this chapter endpoint 3 is specified as defining recovery to climax condition. Figures 1-17 through 1-20 give the recovery sequence for several of the cleanup techniques between the end of cleanup and climax as defined by endpoint 3. See Appendix B for applications.

1.5.1 Unassisted Succession

The vegetation stages leading to the defined recovery, based on information presented in Sections 1.2 and 1.3 of this chapter are summarized below.*

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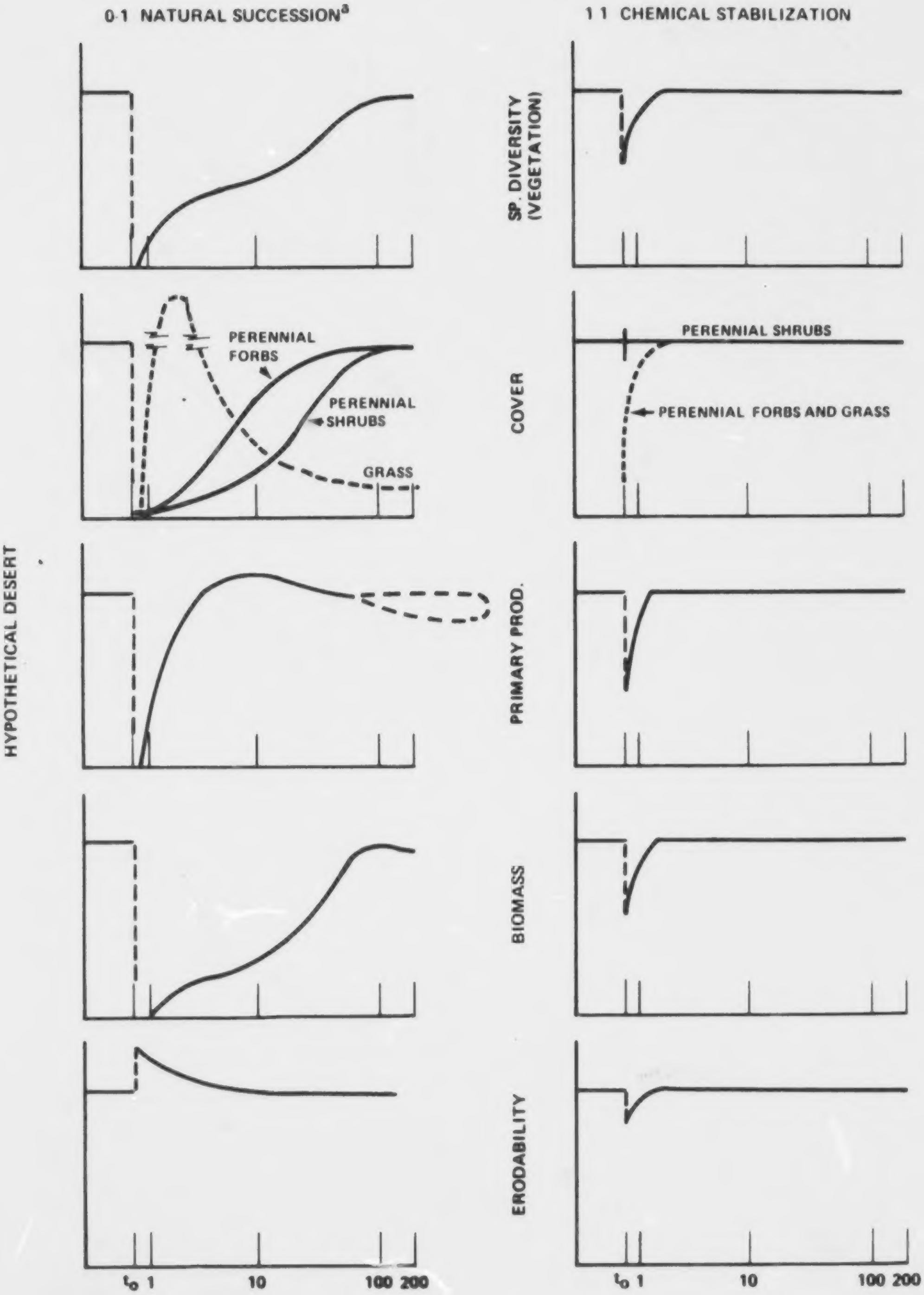
*These stages may not be seral in that the vegetation which forms the pioneer community is present at climax—indeed, the same plants may be present.



[a] Also Scraping and Grading, Remove plow layer, Soil cover <25 cm

Figure 1-17. Sequence of ecologic recovery following cleanup.

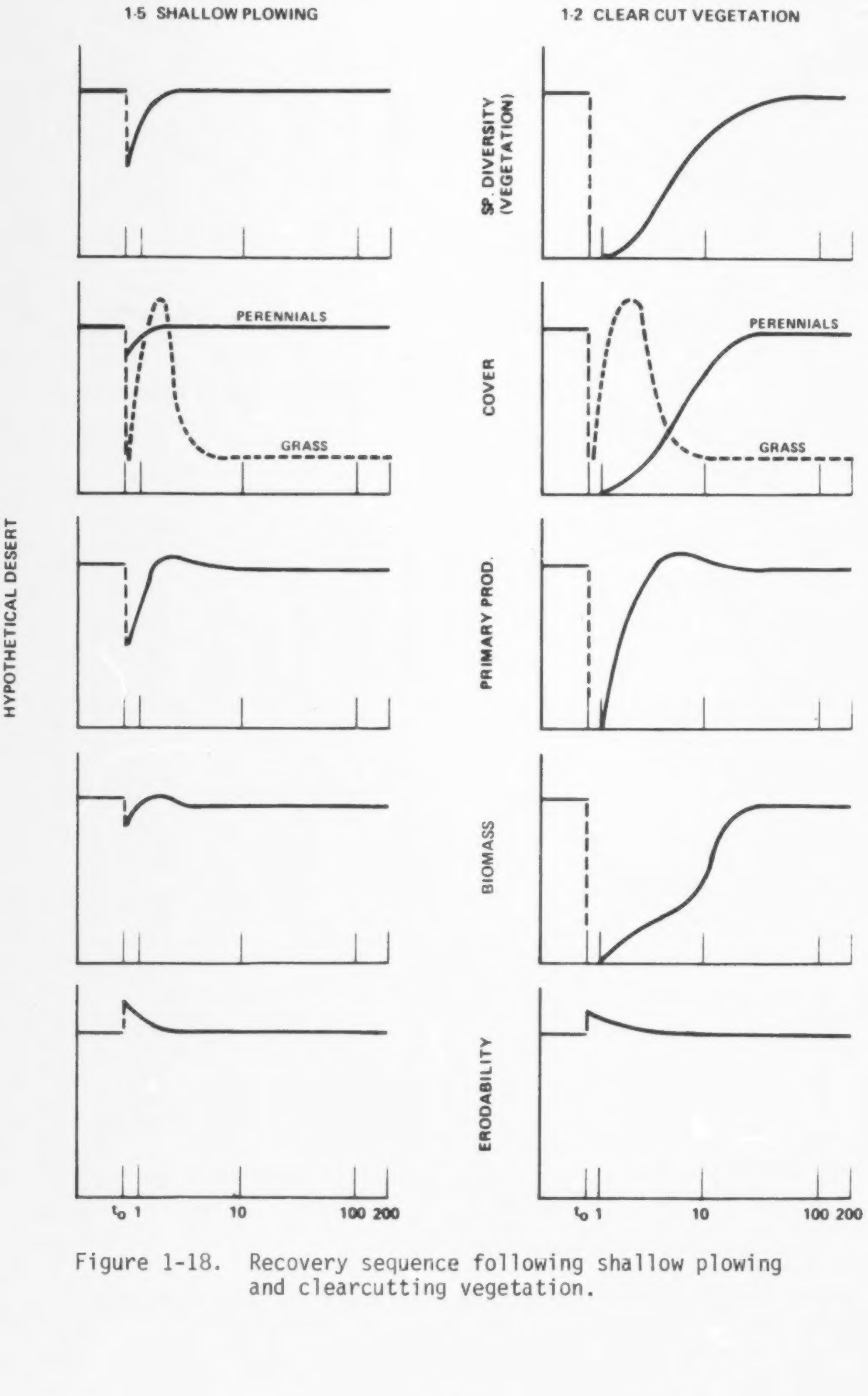
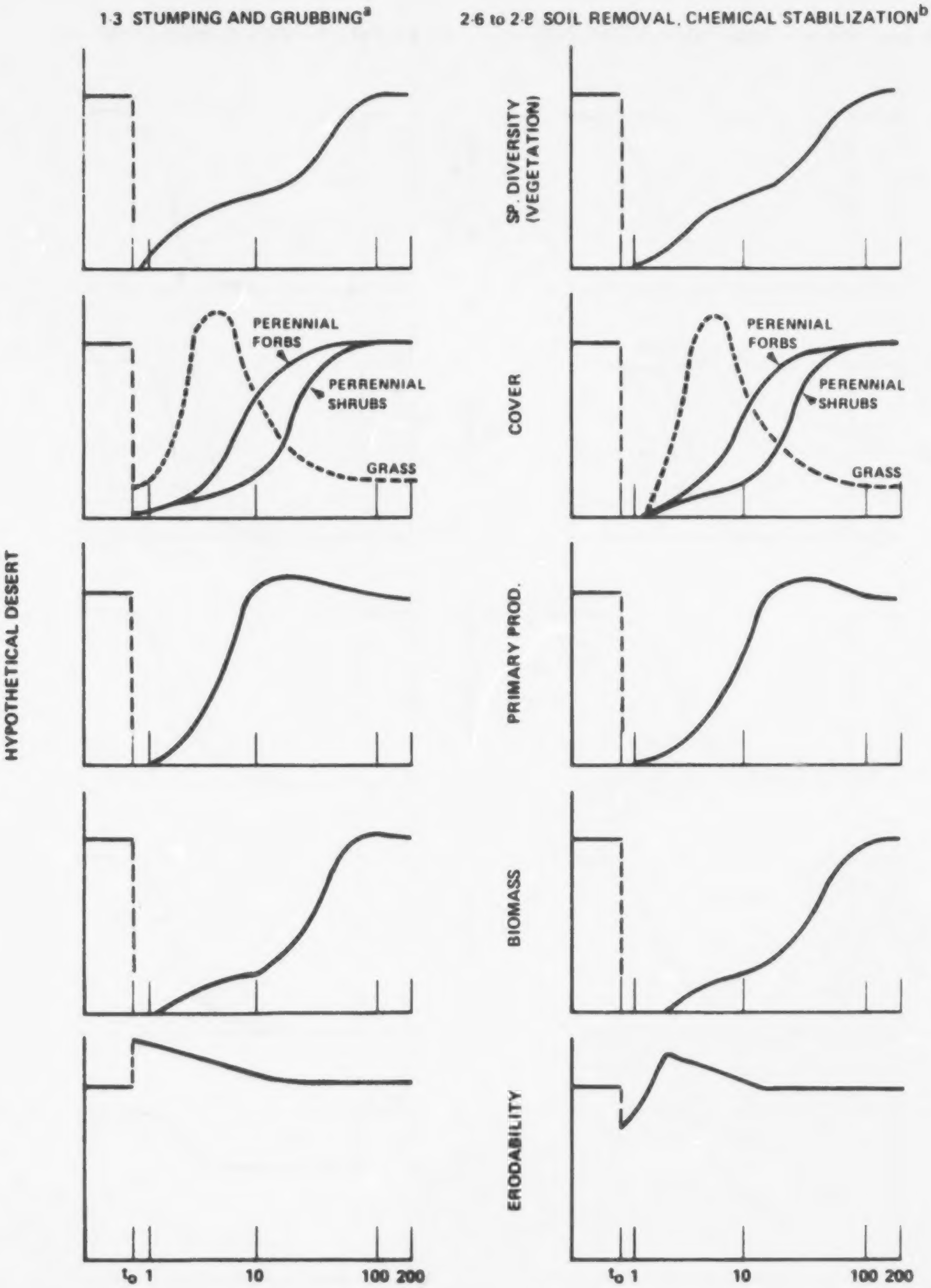


Figure 1-18. Recovery sequence following shallow plowing and clearcutting vegetation.

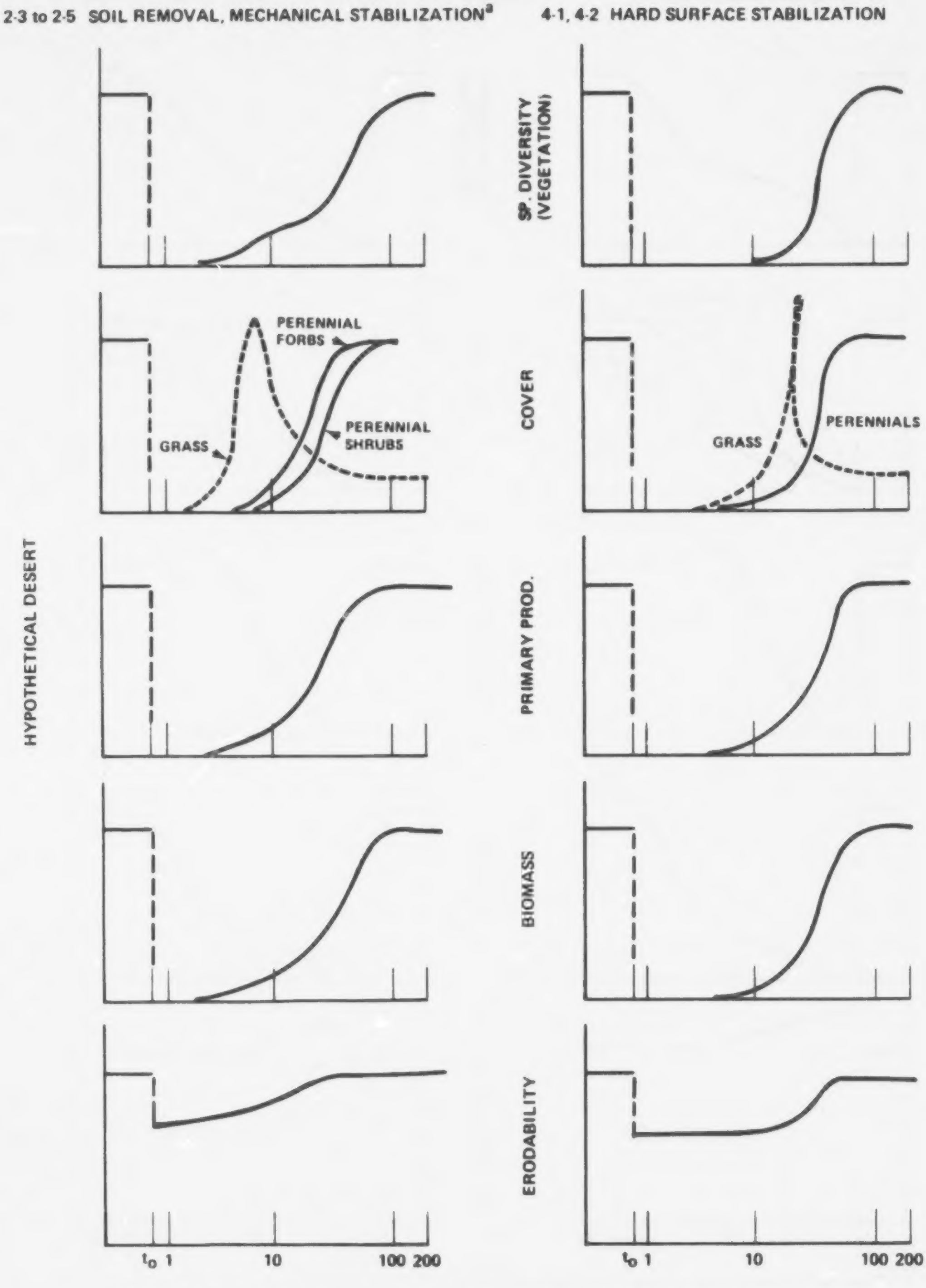

1-3 STUMPING AND GRUBBING[a]

2-6 to 2-8 SOIL REMOVAL, CHEMICAL STABILIZATION[b]

[a] Also, Remove shallow root zone, Deep plowing, Soil cover >25 cm

[b] Includes, Scraping and Grading–Chemically stabilize, Remove Plow layer–Chemically stabilize, Remove shallow root zone–Chemically stabilize

Figure 1-19. Sequence of ecologic recovery following cleanup.



[a] Includes Scraping and Grading–Mechanically stabilize, Remove plow layer–Mechanically stabilize, Remove shallow root zone–Mechanically stabilize

Figure 1-20. Sequence of ecologic recovery following cleanup.

It is assumed that secondary succession begins with bare ground, which contains no particular deleterious edaphic features such as surface clay hardpan or caliche.

Bare ground, if scarified, is invaded by Russian Thistle (Salsola) the first summer following cleanup.[58,59,65,76] During the first year pioneer annuals and grasses appear if adequate moisture is available, otherwise an additional year or two may elapse. The timing of this initial annual colonization is also dependent on the size of the affected area. Areas larger than about 3 km^2 will require an additional year.[74] The introduction of non-native annual grasses is at the expense of native perennial grass.[56] The result of this initial stage in secondary succession is an annual grassland which can persist for decades,[7] or possibly hold at grassland stage by grazing and range management techniques.[56] During this stage the density of grass and ephemerals on the treated area is two to three times that on adjacent areas[7] although the total productivity of the area is lowered[61] largely because older perennial shrubs produce the greatest biomass.[17] There may be a shift in the relative species composition of rodents,[6] which is restored as perennial shrubs reappear.

Starting in the second year—again, assuming adequate moisture—pioneer shrubs characteristic of disturbed sites, e.g., Atriplex, Thamnosma, Salazaria, and Hymenoclea appear.[59,99]

In the third year perennial shrubs which will make up the climax community begin to sprout. Perennial vegetation requires a number of consecutive years of above normal soil moisture and some relief from small animal grazing to become established.[96] Individual plants reach maturity in about 30 to 40 years.[17,96] The area can be expected to have a perennial shrub density of about 20 percent that of surrounding areas in 13 years[7] and about 25 percent in 17 or 20 years.[59,96] Complete recovery of the area should occur in about 80 years.[17,35]

Manipulation of the landscape to create pockets which trap moisture may be used to speed the intermediate stages of succession, i.e., the early perennial shrub stage.[96] Enhancements of shrub density by factors of 2 within these features have been noted[30] but there is a corresponding lessening of density on nearby plots due to restricted soil moisture so the net density for the area is about the same. The landscape manipulation would speed the restoration of the original rodent species composition by providing earlier food and cover for the displaced species.

1.5.2 Cleanup Recovery Categories

From the preceding summary of a hypothetical desert secondary succession and the description of the cleanup techniques presented in Section 1.4, it is clear that there are major divisions in impact among those cleanup techniques that delay recovery, those that result in bare ground with no vestige of organic matter, and those where factors which relate to bare ground recovery are ameliorated. In the first category it is important to note that eventually the bare ground condition is approximated; therefore the time difference in recovery among all the procedures that remove and stabilize the soil is actually the time from the application of the treatment until the bare ground approximation is achieved. The consequences of this outlook are significant, for it implies that once the seed containing layer of soil and the roots of perennial plants are removed, the time to recovery is relatively independent of treatment type. In the last category, recovery from a given cleanup procedure is directly related to the difference between the disruption produced by the cleanup procedure and the bare ground state.

1.6 QUANTITATIVE ASSESSMENT OF CLEANUP IMPACTS

The rationale underlying assessment of the ecological impact of various cleanup techniques is to be able to relate the cleanup procedure to the potential hazard of a contaminant so that the environmental costs associated with the cleanup can be weighed against the benefits of hazard reduction. Since these cleanup techniques will have different levels of efficiency for different types of contaminants, some measure of the impact of each procedure is necessary for this evaluation to be made.

A number of measures are available to estimate the rate of ecological recovery. They are usually in terms of changes in energy cycles, nutrient cycles, food chains, density patterns in time and space, and various control mechanisms. Unfortunately, the interrelationships among most of these in desert ecosystems are largely unknown.

In this section, time of recovery to the climax desert community is taken as a surrogate for ecological impact quantification. Implicit in this measure is the assumption that recovery time integrates the effects of changing primary productivity, species composition of both plants and animals and chemical and energy cycling in the environment. Any other measure of the differential impacts among the treatment types would scale about the same as time to recovery and would produce the same ordering of impacts.

Unfortunately, the measure selected cannot be precise. First, deserts are not homogeneous areas. Local eadphic and climatic factors interact with local variations in plant and animal species to influence recovery rates. Second, recovery is very sensitive to moisture, especially in the early stages of pioneer vegetation growth. This means that the temporal distribution of rainfall, as well as its magnitude, is an important variable. These climatic factors tend to have a greater variance from the mean as the mean decreases. Third, the magnitude of impact depends on the severity of the cleanup in any given situation, for example, shallow plowing was shown in Section 1.5 to be relatively benign. If, however, the perennial vegetation is plowed (a circumstance which might be dictated by local conditions) and if the plowing occurred at such a time that the loosened seed containing surface soil were blown away by winds, recovery would require 40 to 80 years rather than the 12 years estimated.

Table 1-1 lists the median time to complete recovery for each cleanup procedure for various sized areas. There is no clear relationship between size of area and impact listed in the literature; however, the impact is expected to increase as the area increases.

1.6.1 Impact Assessment

For all size areas there is a relationship between severity of impact and magnitude of surface disruption. Soil removal, no matter how slight, constitutes a major perturbation to the ecosystem. Unfortunately, most procedures require soil removal.

The real choices are: first, do nothing other than erect a barrier; second, stabilize or turn under part of the contaminant; third, remove contaminated vegetation; fourth, remove contaminated soil. Choice 1, 2, or 3 would allow time to evaluate expected effects in detail for a particular location, but would be of limited usefulness against a hazardous contaminant that

Table 1-1. Estimates of the years to recover productivity after application of the various cleanup procedures.

Treatment	Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	80	80	80	85	
1-1 Chemical Stabilization	4	4	4	6	
1-2 Remove Vegetation by Clear Cutting	40	40	40	40	70 years for chaining
1-3 Remove Stumps and Grub Roots	85	85	85	90	
1-4 Surface Scraping and Grading (<5 cm)	80	80	80	85	
1-5 Shallow Plowing (<10 cm)	12	12	12	15	
1-6 Deep Plowing (10 to 40 cm)	85	85	85	90	
1-7 Soil Cover (<25 cm)	80	80	80	85	
1-8 Soil Burial (25 to 100 cm)	85	85	85	90	
2-1 Remove Plow Layer Soil (10 cm)	85	85	85	90	
2-2 Remove Shallow Root Zone Soil (<40 cm)	80	80	80	85	
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	95	95	100	105	Assume compaction as mechanical stabilizer
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	95	95	100	105	
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	95	95	100	105	
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	85	85	85	90	
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	85	85	85	90	
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	85	85	85	90	
3-1 Barriers to Exclude People	0	0	0	0	
3-2 Barriers to Exclude Large Animals	0	0	0	0	
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	
4-1 Asphalt Hard-Surface Stabilization	95	95	NA	NA	Assume 15 years to degrade hard surface.
4-2 Concrete Hard-Surface Stabilization	95	95	NA	NA	Assume 15 years to degrade hard surface.
5-0 Sewage Sludge Application	*	*	*	*	
6-1 Washing (<3 mm)	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	
7-0 Soil Amendments Added	*	*	*	*	

*Outside scope of work.
NA - not appropriate for this land type.

could enter man's food chain. The real decision may be between erecting, maintaining, and monitoring a barrier until the contaminant is no longer hazardous, or performing a cleanup procedure whose effects cannot be eradicated naturally for 80 to 100 years and where ameliorative reclamation may be impossible. In one respect this simplifies the cleanup decision since it implies that the only variable which needs to be considered in desert environments is the efficiency of the cleanup procedure.

In summary, cleanup techniques can be grouped into two major categories of severity of impact, each category being further subdivided into groups of slightly differing degrees of impact. In the first category, that of less-severe impact, the group of treatments having the least impact is the erection of barriers (3-1 through 3-3). The next lowest impact group includes those procedures which are less extreme in the degree of bare ground state produced. In this group are chemical stabilization (1-1), shallow plowing (1-5), and clear cutting (1-2). In each of these treatments, the seed-containing layer of soil is not removed, and perennial plants achieve relatively rapid recovery. Ephemeral and annual grass growth is either enhanced or unaffected.

In the second category, that of much greater impact, the first group includes scraping and grading (1-4), soil cover less than 25 cm (1-7), and plow layer removal (2-1), as these procedures result in a bare ground state. Of very similar impact, though slightly greater, are stumping and grubbing (1-3), shallow root zone removal (2-2), deep plowing (1-6), soil cover greater than 25 cm (1-8), and soil removal in combination with chemical stabilization (2-6 through 2-8). The last group, that with the most severe impact, includes the treatments that combine soil removal with mechanical stabilization (2-3 through 2-5), and hard-surface stabilization (4-1 and 4-2), as the resulting soil compaction would further delay forbs and grasses establishment and perennial vegetation germination.

1.6.2 Recovery Assessment

As discussed in Section 1.5, there are major divisions among cleanup techniques with regard to time to recovery. In general, those treatments involving less perturbation to the seed-containing layer of soil will result in shorter recovery times than the treatments which effect the bare ground condition.

Areas with barriers (3-1 to 3-3) will not experience succession in the sense of the other cleanup technologies. The effects of barriers on vegetation are somewhat dependent on the extent of pre-treatment overgrazing but are generally considered to be favorable by increasing the density of plants[8,77,81] and reducing animal-caused compaction.[14,30] The longer an area is protected from grazing pressure, the greater the total number of plants and biomass.[77,81] However, exclusion of large animals might result in changed plant species composition leading to an increase in poisonous species,[10] and containment of rodent populations might lead to massive density fluctuations and a reduction of vegetation biomass.[43] For these treatments, the size of area would have little effect; however rodent population fluctuation would not be expected for the largest area.

Chemical stabilization (1-1), shallow plowing (1-5), and clear cutting vegetation (1-2) can be considered a family of treatments with sequentially increasing recovery time related to the amount of initial environmental disruption. In each treatment the seed-containing layer of soil is not removed, and perennial plants (or their roots) remain to form the basis for relatively rapid recovery. Chemical stabilization affects annual production for one or two growing seasons but should not otherwise alter recovery. Shallow plowing allows most of the perennial shrubs to remain. Scarification of the surface will allow Salsola to become established and reduce erosion, but once the soil is naturally compacted to pre-treatment density and local erosion removes the plow furrows, recovery will be complete. The slightly greater soil moisture found in the plow furrows should enhance ephemeral and annual grass growth; however, even this impact will be unmeasurable within 10 to 12 years. With both chemical stabilization and shallow plowing, it is expected that the recovery time would increase slightly as the area increases over 1 km^2.

Clear cutting vegetation allows perennial plants to resprout from existing roots, thus time to total recovery is shortened and is equal to the time required for a perennial shrub to reach mature stature — about 40 years. The ephemerals and grasses should not be affected by this procedure. Shrubs have been shown to increase productivity when closely cropped.[100] Hand cutting would not result in the surface scarification necessary for Salsola germination. Chaining would disturb some of the seed-containing soil layer and slow the early phases of recovery, but the slowest portion of recovery, regrowth of the perennial vegetation would not be affected and recovery within 40 years can be expected. The size of area would have no effect on recovery time with this treatment.

The procedures of scraping and grading (1-4), removal of plow layer (2-1), and soil cover less than 25 cm (1-7) result in an initial bare ground state and exhibit the same successional pattern and timing as natural revegetation. Full recovery is expected in about 80 years. The size of area is expected to have a slight effect on recovery time as the area size increases beyond 1 km^2.

Four of the techniques, stumping and grubbing (1-3), remove shallow root zone (202), deep plowing (1-6), and soil cover greater than 25 cm (1-8) result in similar recovery patterns. Each treatment is capable of removing or destroying all vegetation and both the A and B soil horizons, therefore total recovery is retarded somewhat by the presumed existence of hardpan on the surface. The hypothetical succession stages and their initiation are about the same as for natural revegetation; however, at any given equal time plant density would be slightly less for these treatments than for natural succession. It is estimated that recovery would occur in approximately 85 years. The size of area is expected to have a slight effect on recovery time as the area size increases beyond 1 km^2.

Procedures which use stabilization in conjunction with soil removal (2-3 through 2-8) result in slightly longer recovery times than the preceding group, but the recovery is not qualitatively different. The chemically-stabilized combination treatments (2-6 through 2-8) result in a delay of the initial invasion phase for a year or two, and climax should be achieved in 80 to 85 years. The size of area is expected to have a slight effect on recovery time as the area size increases beyond 1 km^2. The mechanically-stabilized combination treatments (2-3 through 2-5), exemplified by compaction, would delay the establishment of the pioneer forbs and grasses for 2 to 10 years and would lengthen the time until perennial vegetation germinated to about 15 years. About 90 to 95 years would be required for full recovery. It is expected that increasing area size would increase the time of recovery. Hard-surface stabilization is an extension of mechanical compaction; here, however, no pioneer species can become established until the hard surface begins to degrade. From that point however, recovery will occur in about 80 years.

In summary, to a large extent, recovery time is relatively independent of cleanup technique when the seed-containing soil layer and vegetation roots are removed. The most drastic treatment adds only about 15 percent to the overall time of recovery, compared to natural revegetation.

1.7 CONCLUSIONS

One important topic has not been explicitly addressed. That is, what is the goal of restoration? The goal might be to restore the area to the pre-disturbance ecological community. It might be to establish a similar, though not exact, community, for example, a pure stand of creosote bush in place of mixed perennial species. It might be to change the land use from desert to desert grassland for grazing or even to agricultural land.

Two important factors dominate desert revegetation and ecological recovery of disturbed areas. First, moisture is the critical determinant both of the speed of recovery and the relative dominance of perennial shrubs or perennial grasses. Recovery is usually impeded by the generally low infiltration rate of desert soils so that much of the precipitation is lost as runoff. Second, there is no seral succession; the perennial plants first established form the stable climax community. A mature stable community is normally achieved in about 80 years after a disturbance. Superimposed on these factors is evidence that natural vegetation changes occur in response to long term climatic change, and there is historic evidence that vegetation changes occurred at a time scale that is comparable to that of unassisted revegetation. Successive dry years reduce perennial grass cover, while a series of wet years has the opposite effect. A goal of returning a desert to a pre-cleanup condition may be impossible if, during the restoration period, climatic conditions which existed prior to the cleanup change. A new stable communuty may exist, but it might be different from surrounding communities.

Of the treatments evaluated, several would require thoughtful consideration prior to their use based on their deleterious effect on recovery of the ecosystem. These are: hard-surface stabilization (4-1, 4-2), soil removal followed by chemical stabilization (2-6 through 2-8), removal of the shallow root zone (2-2), soil cover greater than 25 cm (1-8), deep plowing (1-6), stumping and grubbing (1-3), removal of the plow layer (2-1), soil cover less than 25 cm (1-7), and scraping and grading (1-4). As discussed in Section 1.6, the common factor in all of these treatments is the effecting of a bare ground condition; once this happens, recovery time is greatly increased over the time involved for treatments that do not create this condition.

Preferred treatments, therefore, in terms of ecosystem recovery, would be: erection of barriers (3-1 through 3-3), chemical stabilization (1-1), shallow plowing (1-5), and clear cutting vegetation (1-2). Unfortunately, for many postulated materials requiring cleanup, the ecologically preferred treatment may not be the most effective for hazard reduction.

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CHAPTER 2
PRAIRIE

2.1 OVERVIEW

Before overgrazing and cultivation of the 1870's broke the cover, the native grasslands covered between 2.6 and 2.9 million square kilometers of the contiguous United States,[40] or nearly one-third of the land surface. As a general rule, grasslands occurred in areas having between 25 and 75 cm annual precipitation.[22] Less precipitation usually resulted in desert and more resulted in forest; exceptions occurred, however. Tallgrass prairie extended as far east as Ohio (up to 100 cm mean annual precipitation), at least partially the result of recurring fires, and grasses formed the understory of desert shrub communities having as little as 18 cm precipitation per year.

Grassland communities, as the name implies, are dominated by grasses and typically contain little woody vegetation. The grassland growth form is a single, uniform layer of vegetation which does not provide for the variety of niches found in more diverse communities, such as forests.[48] Consequently, the diversity of birds and insects, which can take advantage of vertical stratification, is reduced. Grazing mammals predominate and range from large, running herbivores, such as bison, to a considerable diversity of herbivorous and granivorous rodents.

The term prairie is used in this report to mean midcontinent, perennial grassland. Küchler[17] has identified approximately 15 grassland vegetation types within this region. There is a general increase in cover from west to east which roughly corresponds to rainfall distribution.

2.1.1 Tallgrass Prairie

Tallgrass prairie consists of grasses 150 to 250 cm in height with roots extending to depths of 180 cm or more.[22] The dominant *Andropogon-Panicum-Sorghastrum* association was continuous in the 18th century from Canada to

Oklahoma with tallgrass islands in Wisconsin and east to Ohio, Kentucky and Tennessee. The island prairies were undoubtedly successional stages, for fire prevention in those areas invariably resulted in an increase in woody vegetation. Because of its great agricultural value, little tallgrass prairie remains. One remaining tract, described by Risser,[31] will serve to illustrate a typical association of climatic, soil, and biological characteristics. Mean annual precipitation was 93 cm with 63 cm falling during the 205 day growing season. Mean January temperature was 2.8°C and mean July temperature was 27.8°C. Soils were Brunizems with the A horizon extending to 40 cm and the B horizon to over 100 cm. The list of common plants included the tallgrasses and forbs but did not mention woody plants. The list of common animals was comprised primarily of herbivorous rodents and insects.

2.1.2 Mixedgrass Prairie

The mixed or midgrass prairies are found to the west of the tallgrass prairies in zones of generally lower precipitation. Midgrass prairies average 60 to 120 cm in height. They occur from Canada to northern Texas and the climatic differences yield a variety of plant associations over the range. Midgrasses predominate but both shortgrasses and tallgrasses may be important components. Lewis[19] described midgrass prairie in western South Dakota. The midgrasses Agropyron smithii and Stipa virdula predominated under relief from grazing but there was an understory of shortgrasses, especially Bouteloua gracilis and Buchloe dactyloides. Increased grazing pressure led to a reduction of midgrasses and the formation of shortgrass sod. Mean annual precipitation was 38 cm of which 30 cm fell during a 126-day growing season. Ten year (1958-1967) average temperatures were -1°C (January) and 24°C (July). Annual potential evaporation was high, about 140 cm from a free standing water surface.

In a mixed grass prairie in Kansas,[39] tallgrasses (Andropogon gerardi, Sorghastrum nutans), midgrasses (Andropogon scoparius), and shortgrasses (Bouteloua curtipendula, B. gracilis, and B. hirsuta) all occurred in ungrazed areas. Grazing increased the frequency of shortgrasses. Annual precipitation was 58 cm with a 165-day growing season annually.

2.1.3 Shortgrass Prairie

Shortgrass prairies average 15 to 45 cm in height and occur from Canada to southeast New Mexico and west Texas. A northern shortgrass prairie described by Jameson[15] had Bouteloua gracilis and Buchloe dactyloides as dominant plant species. Annual precipitation ranged from 25 to 38 cm with 80 percent occurring during the summer. Mean January temperature was 4°C and mean July temperature was 29°C. Soils (A + B horizons) ranged from 35 to 76 cm deep. Huddleston[14] described a shortgrass prairie near Amarillo, Texas. Bouteloua gracilis predominated with various other shortgrasses present. Prickly pear cactus (Opuntia polycantha) was abundant with kochia (Kochia scoparia) occurring in disturbed areas. Mean annual precipitation was 53 cm but pan evaporation was nearly 225 cm per year.

2.1.4 Other Grasslands

Outside of the midcontinent plains, major grasslands occurred in the interior of California, as understory to conifers or as openings in the western mountains, and as understory to arid-land shrubs in the interior northwest and southwest.

Küchler[17] considered the native vegetation of the "California steppe" to be perennial grasses of the genus Stipa. Today, these grasslands plus portions of the surrounding, former oak woodlands[45] are dominated by introduced annual grasses, including Avena, Bromus, and Festuca.[40] Climatic data for the California Agricultural Experiment Station's Hopland Field Station indicate great variability from year to year.[11] Mean annual precipitation for a ten-year period was 94 cm, but the range was 63 to more than 150 cm. Summer droughts average 92 days in length and there are an average 70 days with frost each year. Although the five unfavorable months divide the year into two separate growing seasons, the dominance of annuals provides rapid response to community perturbation.

The palouse prairie (shrub steppe) of the Columbia plateau is dominated by Artemesia tridentata, a shrub, and Agropyron spicatum, a bunchgrass. The area is characterized by hot, dry summers and cool, moist winters.[29] Annual precipitation is 25 cm or less. Desert grasslands are superficially similar, being associations of arid-land shrubs and grass understories. Desert grassland near Las Cruces, New Mexico[12] is characterized by a black gramma climax (Bouteloua eriopoda) with various combinations of desert shrubs, including creosote bush (Larrea divaricata) and honey mesquite (Prosopis juliflora).[9] Mean annual precipitation is 23 cm with 55% coming between July 1 and September 30. Characteristic of desert regions, however, is wide variation and unpredictability of annual rains.[21] Several successive dry years reduces perennial grass cover while a series of wet years can have the opposite effect. Pan evaporation is approximately 236 cm annually and mean maximum temperatures range from 13°C in January to 36°C in June.

The vegetation of mountain grasslands varies with numerous factors, such as latitude, altitude, slope and aspect. Van Dyne[40] estimated a total area of 267,731 km^2 from Küchler's[17] data, including that which occurs as understory to ponderosa pine. Site descriptions [20,6] indicate annual precipitation in the range of 33 cm and mean annual temperatures in the range of 7°C. Soils (A + B horizons) may be fairly deep (60 to 110 cm) with the grasses being rooted to the full depth. Agropyron and Festuca are the dominant grasses but many other genera also are widespread.

Many of the proposed cleanup procedures are qualitatively similar to processes, either natural or man-induced, which have gone on previously in grasslands. These have been divided into natural and man-made perturbations, those activities which might be considered disruptive, and range improvement measures.

2.2 NATURAL PERTURBATIONS

2.2.1 Drought

The distribution of plant communities in the central United States in general conforms to the distribution of rainfall. Any long-term changes in the distributional pattern of rainfall would be expected to produce a general shift in the distribution of plant communities. There is evidence that such shifts did, in fact, occur in the past.[10] A broad prairie "peninsula" extended into Ohio during a warm, dry period following the last glaciation, but that prairie was reduced to islands surrounded by forests by the time the first white settlers reached the region. Drought of a lesser extent is characteristic of the prairies and, if of sufficient duration, affects the vegetational distribution. Buffington and Herbel[5] reported that in 1858 over 90 percent of the Jornada Experimental Range in New Mexico was "good grass" while by 1963 less than 25 percent was. Located in a Bouteloua-Hilaria-Larrea association,[17] a slight shift in climate, with continued grazing, resulted in reduced grass cover and an increase in desert shrubs.[12]

The drought of 1934-1936 permitted the invasion of shortgrass and midgrass species into the tallgrass prairie zone. Weaver and Bruner[40] reported on an Andropogon-Poa pasture which was converted to Sporobolus and Bouteloua. Only 8 years were needed for recovery, however, once the drought had ended.

2.2.2 Flooding

The effects of flooding are exactly opposite to those of drought. Periodic floods, as well as ground water percolation, produced flood plain forests well into the shortgrass prairies of Montana and Colorado.[17]

Scifres and Mutz[34] reported on an area of coastal rangeland in Texas which undergoes periodic flooding. The native vegetation is mesquite-acacia savanna in which the dominant grass is Setaria. Low-lying areas (lagunas) may become inundated with fresh water for as long as 5 to 10 years as a result of tropical storms. As the lagunas dry, a mesic sere is established which results in midgrass prairie, often dominated by spike dropseed (Sporobolus contractus). Grazing capacity is doubled, relative to pre-flood stages, but long-term grazing results in reversion to dominance by Setaria.

2.2.3 Fossorial Animals

Fossorial (burrowing) animals are characteristic of grasslands. They include ants and termites, as well as the more conspicuous vertebrates. They all have the net short term effect of setting back the development of both grassland plant communities and soils. This is accomplished through both the direct consumption of vegetation and the burial of vegetation with soil brought up from depths of two or three meters or more.[16]

Abandoned prairie dog towns have been valuable in the study of local successional patterns (seres). Osborn and Allan[23] reported on succession following the decline of a prairie dog town in the Wichita Mountains of Oklahoma. As the colony declined over a 9-year period, it progressively abandoned the outer perimeters of the town until there remained an 8-step representation of the local sere in more or less concentric rings. In the central, active portion of the town, there remained barren soil with a few forbs. On that portion which had been abandoned the previous year grew an annual species of threeawn (_Aristida_). The next stage was also annual threeawn and the next a mixture of annual threeawn and forbs, indicating that the local sere requires three or more years in the annual grass stage. The next stage contained perennial grasses (_Chloris_, _Sporobolus_) as well as threeawn. That was followed by a shortgrass stage dominated by blue gramma (_Bouteloua gracilis_) and buffalo grass (_Buchloe dactyloides_). Next came what the authors called a subclimax midgrass stage, characterized by silver bluestem (_Andropogon saccharoides_) and sideoats gamma (_Bouteloua curtipendula_). The climax vegetation surrounding the abandoned prairie dog town was a tallgrass prairie dominated by _Panicum_, _Andropogon_ and _Leptoloma_ species.

2.3 MAN-MADE PERTURBATIONS

2.3.1 Close Cropping and Grazing

The nonselective removal of grasses, such as by mowing, produces results which differ considerably from selective removal through grazing. When species composition and growing season biomass were studied in an _Andropogon-Panicum-Sorghastrum_ tallgrass prairie near Norman, Oklahoma,[24] it was found that denudation (close cropping and removal of mulch) had no significant effect on species composition when compared to the control. Net primary production (NPP, biomass produced during a single growing season) was greater in the denuded plots than in controls, however. Slightly different results were reported by Weaver and Rowland[42] for tallgrass prairie in Nebraska. They compared the prairie growing on an abandoned dirt road with adjacent grazed or mowed fields. Again they found that yields (NPP) were 25 percent to 50 percent less in the climax prairie growing in the abandoned roadway than they were in the grazed or mowed fields. However, they found a relative increase in the frequency of occurrence of

Andropogon in the roadway. Since mowing is nonselective, they attributed the increase in Andropogon to accumulation of natural mulch (see Section 2.3).

Grazing animals tend to select the plant species they consider to be most palatable with the result being that intense grazing usually produces a shift in species abundance. In mixed grass prairies, grazing can result in shortgrass species replacing midgrass species,[19,38] and in a general decrease in canopy height.[46] In more arid regions, intense grazing pressure favors the establishment of desert shrubs and can interfere with reclamation attempts.[13]

2.3.2 Compaction

The short-term effects of compaction are all negative. The primary effect is to increase bulk density of the soil (weight per unit volume) which decreases infiltration of water, reduces water storage capacity, reduces aeration, inhibits root penetration and restricts movement of soil animals.[26] These effects are most severe in moderately wet soils and in those with a higher clay, but they can be significant in coarse-textured, arid-land soils as well.[8]

The effects of compaction are not irreversible, however. Stipa-bunchgrass stands may be found growing on the streets of a Nevada ghost town[44] and climax tallgrass prairie was reported to have been established 15 years after the abandonment of a dirt road in Nebraska.[42] Factors affecting the rate of recovery from compaction include soil type, climate and presence or absence of surface sealants.

2.3.3 Plowing

The effects of plowing are in many ways similar to the activity of prairie dogs. Vegetation is killed and soil is turned over. The major difference lies in the fact that deep, organic-poor soil is not deposited on the surface by plowing. Most of our understanding of plant succession has come from the study of abandoned agricultural land, most of which had been plowed for one or more years.

2.3.4 Natural Succession

Succession in tallgrass prairie can be extremely rapid, especially if a suitable seed source is readily available. Rice and Penfound[27] reported an experiment carried out in an Andropogon-Sorghastrum-Panicum prairie in Oklahoma. In the first year after plowing, Ambrosia psilostachya (a ragweed) was the most important dominant. By the second year, the dominants in the control had replaced the ragweed. The authors concluded that "succession back to the prairie stage was, therefore, extremely rapid under the conditions of the experiment."

The fruits of grasses tend to be windborne and the fruits of pioneer species tend to be carried further than those of climax species. Consequently, increasing the size of the disturbance tends to lengthen the time required for succession. Rice, et al.,[28] indicated that the fruits of triple awn (Aristida oligantha) are carried great distances and triple awn is typically the first invader in disturbed tallgrass prairie. Little bluestem (Andropogon scoparius) fruits are windborne only about 2 meters and thus may take several generations to reach the center of a large old field.

A typical tallgrass prairie succession was given by Perino and Risser.[25] Following abandonment of a cultivated field in Oklahoma, a weed stage is established which persists for two or three years. This pioneer stage is characterized by Ambrosia, Sorghum, Bromus tectorum, and Rumex. The weed stage is followed by an annual grass stage lasting 9 to 13 years and is dominated by Aristida oligantha, Aster sp., Ambrosia sp., and Andropogon saccharoides. A perennial bunchgrass stage dominated by Andropogon scoparius follows and can last 30 years or more. Tallgrass prairie climax becomes established after 40 to 50 years and consists of Andropogon gerardi, A. Scoparius, and Panicum virgatum. The weed stage is characterized by a predominance of live vegetation (51%) which declines to 26 percent at climax. Standing dead increases from 28 percent in the weed stage to 32.5 percent in the bunchgrass stage and declines to 17 percent in climax. Litter increases throughout the sere from 21 percent to 57 percent. Areal cover declines from the weed stage to the annual grass stage but increases through the rest of the sere.

2.3.5 Range Improvement

2.3.5.1 Mulches--

Mulches increase soil moisture through increasing infiltration of precipitation and reducing runoff and evaporation. Soil moistures and temperatures are stabilized and the conditions for germination of grass seeds are improved.[38] The effects of natural and synthetic mulches are similar, but effectiveness may vary with the grass species,[1] growth stage of the grasses,[42] and local climate.[3] In desert grassland,[3] an increase in soil moisture of 20 percent, due to mulch, increased forage production by 50 percent. In climax tallgrass prairie, however, naturally-occurring mulch was said to have reduced yields by 25 percent to 50 percent as compared to mowed or grazed fields where mulch did not accumulate.[42] In addition, application of mulch can reduce the frequency of less desirable species, such as ragweed, by improving the conditions for emergence or growth of the desired grass species.[27,1]

2.3.5.2 Seeding--

Seeding of desired grass species offers several advantages over dependence on natural recovery. First, it is often possible to bypass succession and seed directly to climax. Riegel, et al.,[30] seeded with climax species in west-central Kansas and noted no differences in yields over a 17-year period when compared to native grassland. In other cases, selective seeding can actually improve the range quality. Rumsey[33] reported forage yield increases of up to 300 percent in 7-8 years in an Agropyron/Artemesia association. Seeding is not a simple proposition, however. Bement, et al.,[2] were more successful with introduced species than they were with native grammas, whereas Terwillinger and Jensen had their greatest success with the grammas and other native species. Seeding success or failure depends upon a number of factors, many of which are beyond direct control. Terwillinger and Jensen[37] found seeding in shortgrass prairie to be successful only when the precipitation to evaporation ratio was 0.3 or greater. Once the seed has germinated, sufficient ground cover must be achieved before a periodic dry year to avoid wind erosion around the roots. In drier areas, e.g., desert grassland and shrub steppe, probability of seeding success declines unless extraordinary measures are taken, such as water entrapment, reduction of competition from woody vegetation, delay of grazing, mulching, and rigid seeding standards.[13]

2.3.5.3 Shrub Removal--

In 1858, over 90 percent of the Jornada Experimental Range in New Mexico (Desert Grassland) was in good grassland range and by 1963 that figure had declined to less than 25 percent.[5] Climatic change may have been partly responsible but grazing pressure on the grasses certainly gave a competitive advantage to the shrubs. Range restoration[13] included plowing to 9 inches to kill the shrubs, seeding, and moisture trapping. In addition to range restoration, new range has been created from shrubland by clearing of shrubs and seeding with appropriate grasses.[50]

2.3.5.4 Moisture Trapping--

Twenty-five centimeters annual precipitation is generally considered to be the minimum required for successful revegetation of disturbed lands; less requires intensive management including irrigation and fertilization.[9] Reclamation and improvement of desert grasslands is further impeded by generally low infiltration rates so that much of the precipitation received is lost as runoff. Seeding success and production of herbage have been improved through the construction of pits which trap runoff and allow a greater time for infiltration. In southern Arizona where annual rainfall averages 15 to 20 cm, moisture penetration averaged twice as deep and herbage production was five times greater when pits were employed as compared to adjacent flats.[36] In a Utah salt desert, Wein and West[43] found that moisture entrapment was essential to survival of crested wheatgrass (Agropyron cristatum) seedlings even if there had been sufficient rainfall to produce germination without entrapment.

2.4 EFFECTS OF CLEANUP PROCEDURES ON PRAIRIE

This section describes the effects that imposition of certain contamination cleanup treatments produce on prairie ecosystems. Qualitative descriptions of the effects caused by each cleanup treatment are related in this section; the quantitative assessment of the impacts of cleanup on prairie ecosystems is given in Section 2.6 with estimates of the relative times for a return to the native ecosystem. Recovery time projections are based upon the presumption that, if man were restrained from interfering, plant succession would go forward under the vegetative potential at the site and climate to recreate a prairie. Reclamation procedures and other "management" of prairie sites is discussed in Chapter 8.

Three groupings of the cleanup procedures can be seen in this section. First is cleanup that provides temporary holding of a contaminant in place. Second are procedures that remove the physical contaminant and stabilize the site until renovation occurs, and third are alternatives to holding and removing the contaminant.

(0-1) Natural Rehabilitation

No significant impacts are expected to remain more than two or three years after manual cleanup. Annual grasses will occupy the shoveled and scooped-out excavations during the next growing season and that may be the entire sere. No "area" effect is anticipated. The extrapolation is one of a succession of "pock-marks."

(1-1) Chemical Stabilization

When vegetative cover is removed, soils become subject to accelerated erosion by both wind and water. The various stabilization practices may tend to retard the initial stages of revegetation. Chemical stabilizers form a less permeable surface layer which reduces infiltration of water and may also prove to be a physical barrier to seed germination. Further, dark-colored emulsions may increase soil temperatures above the range of tolerance for germinating seeds. With time, however, cracks tend to develop in stabilized areas which both allow seeds to germinate and channel runoff to seeds sprouting in the cracks. As natural rainfall decreases, cracks in soil sealants can provide micro-habitats which support relatively vigorous growth. In prairies, however, sufficient moisture to permit revegetation is usually available and stabilization techniques which retard revegetation must be viewed as negative, long-term impacts.

The properties of two groups of soil additives, 1) chemical stabilizers and 2) chemical stabilizers with mechanical properties, are given in Appendix A, Stabilizers. Eleven of the chemical stabilizers are rated "preferred" for prairie use, 10 of these require post-application site renovation for plant regrowth; 7 of the 25 'preferred" chemical stabilizers with mechanical properties permit immediate natural regrowth of vegetation. All eight of the preferred stabilizers are rated to break down in a year or less after application.

(1-2) Clear Cutting Vegetation

Clear cutting of grasses (mowing) and removal is a common practice with well-documented results (Section 2.3). Since the process is nonselective, there are virtually no effects on species composition and, in the short term, productivity is actually increased. On shrub-free grasslands, effects of mowing and removal would probably not be discernible with a single growing season. The presence of woody shrubs, however, increases the impact of clear cutting. Woody plants have their meristematic (growth) tissues located at the tips of branches as opposed to at ground level in grasses. Clear cutting thus removes the primary growth tissues resulting in longer recovery times. Most woody plants do have the ability to form stem tissue at the roots (root-sprouting) so that clear cutting may have no profound effect on long-term community composition. A one-time clear-cut would allow woody plants to resprout using food reserves stored in the roots but, as farmers well know, repeated cuttings deplete stored reserves and eliminate the woody component.

(1-3) Stumping and Grubbing

"Stumping and grubbing" of grasses, that is, the removal of a major portion of the root system, is not possible, owing to the diffuse nature of their root systems. The procedure will prevent root sprouting of shrubs and will prolong the period needed for complete recovery. Since reestablishment of shrubs would then depend on reseeding, the size of the area treated would be proportional to recovery rate. A secondary impact would be the effect of the treatment on the area's attractiveness to wildlife. Grasses, generally, produce a single vertical stratum which limits the number of niches available to bird species. As shrubs and trees are added to grasslands, the number of strata increases resulting in increases in bird species diversity. Removal of shrubs, trees, or both could produce losses of bird species lasting decades or more and could possibly lead to the eradication of species already faced with limited habitat. A detailed discussion is deferred to Chapter 10.

Positive results of shrub removal would include improvement of pasture for cattle. Following the discussion above, it is apparent that improvements would persist longer as size and severity of the treatment are increased. Further, seeding success of shrubs would initially be reduced by the presence of the grasses but, once established, shrubs are successful competitors of grasses. The presence of cattle yields a favorable competitive balance to shrubs since cattle will selectively remove grasses, when they are available.

(1-4) Scraping and Grading

Surface scraping and grading of the upper 5 cm of grass roots and soil could reasonably be expected to have only a moderate effect on grassland ecosystems. In the prairies, ground irregularities would preserve the meristematic (growth) tissues of a portion of the grass plants allowing relatively rapid recovery. Soil compaction, if done with crawler tractors, could possibly have a greater impact than the blading itself. In mountain grasslands, shrub steppe and desert grasslands, blading would remove the woody component yielding a significant change in community structure. Release from competition could result in an increase in grass cover in arid zones with a corresponding increase in animals utilizing grasses. The number of niches would be decreased, however, with a resultant displacement of the birds and insects which require vertical heterogeneity in a plant community. Taking the extreme examples, 0.01 km^2 and 10 km^2 of blading, the lesser disruption would produce effects probably too slight to measure while the larger could have significant effects. The significant effects could be both detrimental, such as long-term loss of bird species, and beneficial, such as range improvement for domestic livestock.

(1-5) Shallow Plowing

Shallow plowing (<10 cm) will not penetrate the sod layer of most grasses and would probably do no more than break off woody plants, allowing them to resprout. It is not likely to be used as a clean-up procedure and if used is not likely to have much impact.

(1-6) Deep Plowing

Deep plowing (up to 40 cm) would result in complete removal of the ecosystem with succession starting from bare ground. This is the perturbation that farming represents and is the best known event leading to secondary succession (Section 2.3).

(1-7) Soil Cover Less Than 25 cm

A number of factors can affect the outcome of adding soil cover to the community. With shallow coverage (<25 cm), quality of soil applied, actual depth, and plant community would all affect impact level. The more shallow the soil cover the less disturbance would occur, generally. In a mixed plant community, woody vegetation would tend to be disturbed less than grasses. In either case, grasses recover more quickly. The addition of porous topsoil would have less detrimental effect than adding subsoil, since the roots might still receive sufficient aeration.

(1-8) Soil Cover 25 to 100 cm

There is probably no difference between adding 25 cm or less soil and up to 100 cm. Even the smallest area to be covered, 0.01 km^2, would require 2500 m^3 of soil for coverage to 25 cm. Expediency would undoubtedly result in coverage with any soil available with the result that effectively all of the vegetation would be killed. Thus, burial would result in a successional starting point similar to scraping and grading (1-4), plowing (1-5, 1-6) or soil removal (2-1, 2-2).

(2-1) Remove Plow Layer

Soil removal is a radical perturbation to an ecosystem. Removal of the plow layer (∿15 cm) would have an increasingly serious impact with decreasing mean annual precipitation. In tallgrass prairie, the effect could be no more serious than plowing, for the A soil horizon extends well below that depth (Section 2.1). In shortgrass prairie, removal of the plowed layer could result in virtual loss of the A and B soil horizons with long-term impairment of the production capability of the soil.

(2-2) Remove Shallow Root Zone

Removal of the shallow root zone in tall- and midgrass prairies is almost a contradiction of terms due to the depths to which grasses are rooted (Section 2.1). Shallower soils, such as some shortgrass prairies, desert grasslands and mountain grasslands, could be removed down to C-horizon material if 30 cm of soil or more were removed. This would result in revegetation problems analogous to deep cuts along roadways or spoil-bank reclamation. Comparable removals in tallgrass prairie might shorten the projected cultural lifetime (i.e., number of centuries which the land might be tilled successfully) but the short-term (e.g., decades) effect might be indistinguishable from the effects of plow-layer removal.

In either case, as with scraping and grading (1-4) and plowing (1-5, 1-6), the complete removal of vegetation and exposure of soil would lead to predictable erosional losses. Water erosion potential is obviously greater under the higher precipitations and storm-intensities found in the more eastern grasslands. These losses should not exceed normal agricultural losses on a scale of 0.01 to 0.1 km^2 and, depending on locality, possibly over 1 km^2. At the 10 km^2 scale, however, significant increases in erosional losses may be anticipated, for it would be hard to imagine landscape units of that magnitude which did not include major drainages. Thus, complete removal of the soil or its retaining vegetation would effectively prohibit sedimentation from occurring prior to entry into major drains.

Potential losses from wind erosion increase both with increases in the size of the barren area and with the reciprocal of the square root ($1/\sqrt{r}$) of surface soil moisture.[49] Again losses would be comparable to normal agricultural losses when the area disturbed was similar in size to agricultural fields. Plowed fields are typically broken up with trees planted for windbreaks, the removal of which would increase soil losses exponentially since the sheltered zone is calculated as ten times the height of the trees.

(2-3) Remove Scraping and Grading, Mechanically Stabilize

Removing less than 5 cm of soil impacts prairie ecosystems less than removing a shallow plow layer (2-1). The mulch layer would be taken, with a reduced impact on seed stores, soil tilth, and fertility, but wind erosion effects could be approximately equal. Wind erosion on bared, prairie soil is precipitation dependent. For prairie with low precipitation (shortgrass) the length of unobstructed wind run and soil particle aggregation at the exposed surface become critical factors that determine the site wind erosion potential in dry seasons of the year. In tallgrass prairie climates, soil losses by wind erosion are normally minimal.

Stabilization is attempted to retard erosion, a desired result, but carries with it a slowing of plant establishment, an undesired result. Mechanical and chemical stabilization perform differently. Mechanical stabilization compacts the soil while chemical stabilization binds soil particles together. Either is accomplished by a number of methods or chemical agents, all with qualitatively the same results relative to plant establishment and growth. The properties of stabilizers are evaluated in Appendix A, Stabilizers.

Few mechanical stabilizers are rated "preferred" for prairie soils in Appendix A, including deflocculants, clays, and membranes. Natural and synthetic rubbers, polyethylene and vinyl membranes, paraffin wax, plus asphalt emulsions exhaust that list, and only the asphalt emulsion permits regrowth of plants the next season.

One popular method of mechanical stabilization depends on soil clay and physical compaction to make an impervious surface. This may compress soil sufficiently in making the physical barrier that it prevents subsequent seed wetting and seedling emergence and revegetation. Soil moisture input through the compacted layer is decreased by two conditions. Permeability to surface water is seriously impaired by pore space reduction and a shortening of infiltration opportunity occurs because of faster runoff from the smoothed surfaces. Runoff can readily become 70% of annual precipitation. The effects on revegetation, in principle, are similar among deflocculants, added clays, and direct surface compaction. Heavily treated areas are toxic to plants but are likely to be breached in a few months by resident small rodents. The composite effects of surface soil compaction are intermittantly visible in reduced vegetative growth for decades afterwards (Section III).

The use of meshes and mulches to reduce erosion are described in Sections 4.4 and 8.4 of Chapters 4 and 8.

(2-4) Remove Plow Layer, Mechanically Stabilize

Revegetation potential at the cleanup site will be partially reduced compared to plowing (1-5, 1-6), by loss of seed sources, mulch layer and the upper fertile A-horizon. The significant revegetation impact is caused from compaction by stabilization and its effect on water infiltration and seed emergence. The smoothed surface allows rapid runoff with the possibility of water concentration leading to piping and gully development on long overland runs. The high organic matter will make stabilization more difficult. Physical retardation of seedling emergence limits early revegetation to shrub crown sprouts. Gradually frost heaving, aided by localized punctures of the surface by shrubs and small rodents, will be effective in opening the surface to serious erosion; runoff water erosion in tallgrass and eastern midgrasses and wind erosion at western mixed grass and shortgrass sites. This treatment becomes a degraded version of 2-1. Chemical stabilization is preferable in the eastern prairie.

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

Treatment 2-2 has defined the ecological effects of removing 40 cm of prairie soils and the mechanical effect of stabilizing was covered in Treatments 2-3 and 2-4. This cleanup has severe side effects on shortgrass soil profiles because most of the B horizon will be removed and with it much of the fertility needed for revegetation. On these westside soils renovation is required before succession toward grasses will begin. This is next to the most severe treatment on prairie.

(2-6) Remove Scraping and Grading, Chemically Stabilize

This composite treatment appears similar to treatment 2-3 but is much less drastic. In some respects it has an impact equivalent to windrowing of the surface which might be done in 1-4. While there is a loss of surface seed stores, the potential for erosion is reduced by chemical stabilization while revegetation is started. Breakdown of chemical stabilizers occurs in the next growing season if one of the preferred treatments from 1-1 is applied. Revegetation should have produced a crop of annuals in the grasses and crown-sprouting of shrubs should be well underway. Because these stabilizers are limited to relatively small areas (Appendix A) natural seeding should suffice.

(2-7) Remove Plow Layer, Chemically Stabilize

The effects of removing 10 cm of surface sod present some problems to cleanup crews. Using a turf-cutter would be the most likely procedure but its decontamination effectiveness would be limited by micro-depressions and contamination inside burrow tunnels. Plowing was described in Treatment 1-5 and those comments apply. The net effect of removing the plow layer to 10 cm would be quite similar to Treatment 2-6 just described and have the same impact on soil fertility. The impacts would be greater in shallow soils where the plow layer is deeper than the A horizon. The prospects for revegetation would be impaired to a minor degree.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

This is a radical treatment because of the removal of the fertile, plant-supporting medium on many sites and exposure of the C horizon in shortgrass prairie. The application of chemical stabilizer to small areas as wind-erosion protection can be tolerated but revegetation potential seems similar to 1-6, starting from bare ground. Severe wind erosion should be expected in 2 or 3 years.

(3-1) Barriers to Exclude People

Fencing of a contaminated area to restrict movement of man and other animals has been proposed as an alternative to decontamination, at least temporarily. Generally speaking, barriers can prevent direct contamination but can be ineffective in preventing contamination by way of the food web.

(3-2 Exclude Large Animals)

Fences designed to exclude cattle and other large grazing mammals will block one direct link in the food web leading to man. The release from grazing pressure will not necessarily be a desirable impact on the grassland ecosystem, for the resulting increase in standing dead organic matter and mulch will have a tendency to reduce primary production. Large exclusion areas would prove to be an economic burden to the local population and possibly a detriment to migrating wildlife. Otherwise, the species diversity and stability of the ecosystems would not be significantly affected and will not be treated further.

(3-3) Exclude Large and Small Animals

The effect of barriers to exclude small mammals (rodents, etc.) will be dependent, at least in part, on the size of the area fenced. Small areas, on the order of 0.01 km^2, may prove to be too small to support viable populations. The resultant release from rodent, as well as large mammal, grazing pressure could possibly begin to affect the rate of return of nutrients to the soil and overall community stability. Such a small area is not likely to be unique and, if not, the loss cannot be considered to be significant. Large areas, on the order of 10 km^2, would contain self-supporting populations of small mammals and would be largely unaffected by barrier erection. Gene flow and genetic plasticity could become affected, in time, but insufficient data exist to evaluate this effect.

Neither birds nor insects can be effectively controlled by barriers. In the case of upland game birds, such as ring-neck pheasants, feeding in the contaminated area could lead to direct contamination of man. However, insects are sufficiently small and far removed from the human food web, so unless the contaminant is extremely mobile, contamination by way of insects is unlikely, although some insect vectored contaminents might prove toxic to migratory birds.

(4-1) Asphalt Hard-Surface Stabilization

Decomposition of 3-inch-thick, unsupported hot mix asphalt requires more than 10 years in the midgrass prairie on sandy soils when trampling by cattle is prevented. In the meantime, reinvasion by stands of grasses is blocked until the asphalt fractures or the surface cracks. The retardation of revegetation is absolute but if soil moisture conditions were right at the time of surfacing cold weather frost heaving can fracture the asphalt enough to allow seed penetration, and germination and growth in the next season.

Where shrubs intermingle with grasses the likelihood of puncture by root- or crown-sprouts is high. Holes made by the sprouts and the new shrubs act as collection points for debris, weed and grass seeds, and soil. Seeds germinating in the drift piles speed breakup and weathering of the asphalt around the punctures. Those local species that normally reproduce from seed should remain at these breaks.

Soil compaction by the tank trucks and heavy trailers needed for asphalt surfacing would be evident more than a century later as demonstrated by bison wallows and trails. Hydrological impacts generated by the hard surface would equal those described for Treatments 2-3, 2-4, and 2-5, but the site preparation impacts are greater than those treatments cause.

The gross effect of the asphalt hard surfacing is to delay for a decade or more, beyond the delay caused by Treatment 2-5, the entry of the site into the prairie sere. The treatment might be tolerated in shortgrass prairie as a secure, temporary cover to minimize redistribution of contamination, the certainty of breakup in a few years makes that use highly questionable. The potential for gully creation in the relatively mesic tallgrass prairie precludes use there anytime.

(4-2) Concrete Hard-Surface Stabilization

Covering a site with concrete deals the ultimate impact among those cleanup treatments proposed. All the disadvantages of asphalt surfacing plus the several times greater durability of concrete chunks and blocks make later uses contingent on removal of the concrete. This would be exceedingly expensive in either transportation costs or onsite burial.

2.5 RECOVERY AFTER CLEANUP

2.5.1 Irreversible Changes

No irreversible changes are anticipated with scraping and grading, plowing, vegetation removal or flooding. Each falls within the range of analogous perturbations (discussed in Sections 2.2 and 2.3 for which successional information exists. Whether or not irreversible changes (i.e., failure to reestablish a similar community within 25 years or more) would occur as the result of soil removal or burial would depend upon local conditions and the extent of perturbation. In most cases, no irreversible changes would be anticipated for removal of the plow layer of soil or if suitable soil were used for burial. In more extreme cases, such as on shallow mountain soils, in the most arid margins of grassland distribution or where burial was with particularly low quality material, extraordinary reclamation procedures might be required for successful reestablishment of vegetation. These might include the land management practices (Chapter 8) of water entrapment, irrigation or addition of soil amendments. It should be noted, however, that reestablishment of vegetation on a site does not imply lack of irreversible changes, nor does irreversible change imply complete loss of a resource. The change may lower productivity and prevent recovery of climax by establishing an entirely different flora than the displaced grasses.

2.5.2 Rates of Recovery Following Cleanup

Rates of recovery are affected by several factors, including severity of perturbation, proximity to seed source, local climate and soil conditions. In general, recovery will be most rapid the less severe the perturbation, the smaller the area involved and the greater the normal rainfall. In the discussion that follows, certain caveats are appropriate. Conclusions will be drawn for major plant associations such as tallgrass prairie, which may cover on the order of 10^5 km^2. The data supporting those conclusions are drawn from studies which represent small samples from within the larger association and typically do not begin to cover the range of possible seres. In a few instances, appropriate seres simply have not been documented and it has been necessary to extrapolate from the most similar situations that could be identified. It is, therefore, assumed that this analysis will be useful in formulating policy but that field-level decisions will require site-specific information

Idealized trend curves were developed as guides to illustrate the time course of recovery to full productivity for some of the prairie ecosystem parameters. The ordinates are without units either because they have no dimensions (e.g., homostasis) or they are broad generalizations over the array of heterogeneous prairie sites. Representative cleanup treatments were selected for the illustrations. Assisted and unassisted recovery are shown in Figure 2-1; recoveries of grasses and woody elements are illustrated in Figure 2-2, and in Figure 2-3 the maximum contrasts in impact effects are shown.

2.5.2.1 First Year Following Cleanup--

With at least two cleanup procedures, mowing and fencing (clear cutting and barriers), prairies should attain complete recovery within one year. Penfound[24] reported that denudation resulted in no significant change in species composition and actually resulted in an increase in biomass. Since "stumping and grubbing" are inappropriate for prairies, denudation would consist only of mowing and removal of biomass. Complete recovery can, therefore, be assumed after one year. Size of area mowed would have no effect.

If a suitable seedbed remains after cleanup, prairies may be seeded directly to climax,[30] thus providing for near recovery the first year. This would include scraping and grading, plowing, and most instances of soil removal where some A horizon is left as a seed bed. The addition of nitrogen fertilizer can aid establishment of perennial grasses[32] especially if sufficient moisture is present.[9] Size of area is unimportant.

Assuming a suitable seedbed remains but with reliance on natural revegetation, then the size of the area disturbed becomes important. Rice, et al.,[28] reported that the seeds of a climax species were windborne only about 2 m while the seeds of an early invader were carried a great distance. Thus, assuming seed sources completely surround the disturbed area and no differences exist due to prevailing wind direction, in one year seeds of the climax species might reach 7 percent of a 0.01 km^2 circular plot (the configuration for maximum potential invasion under the stated conditions). The area invaded declines to

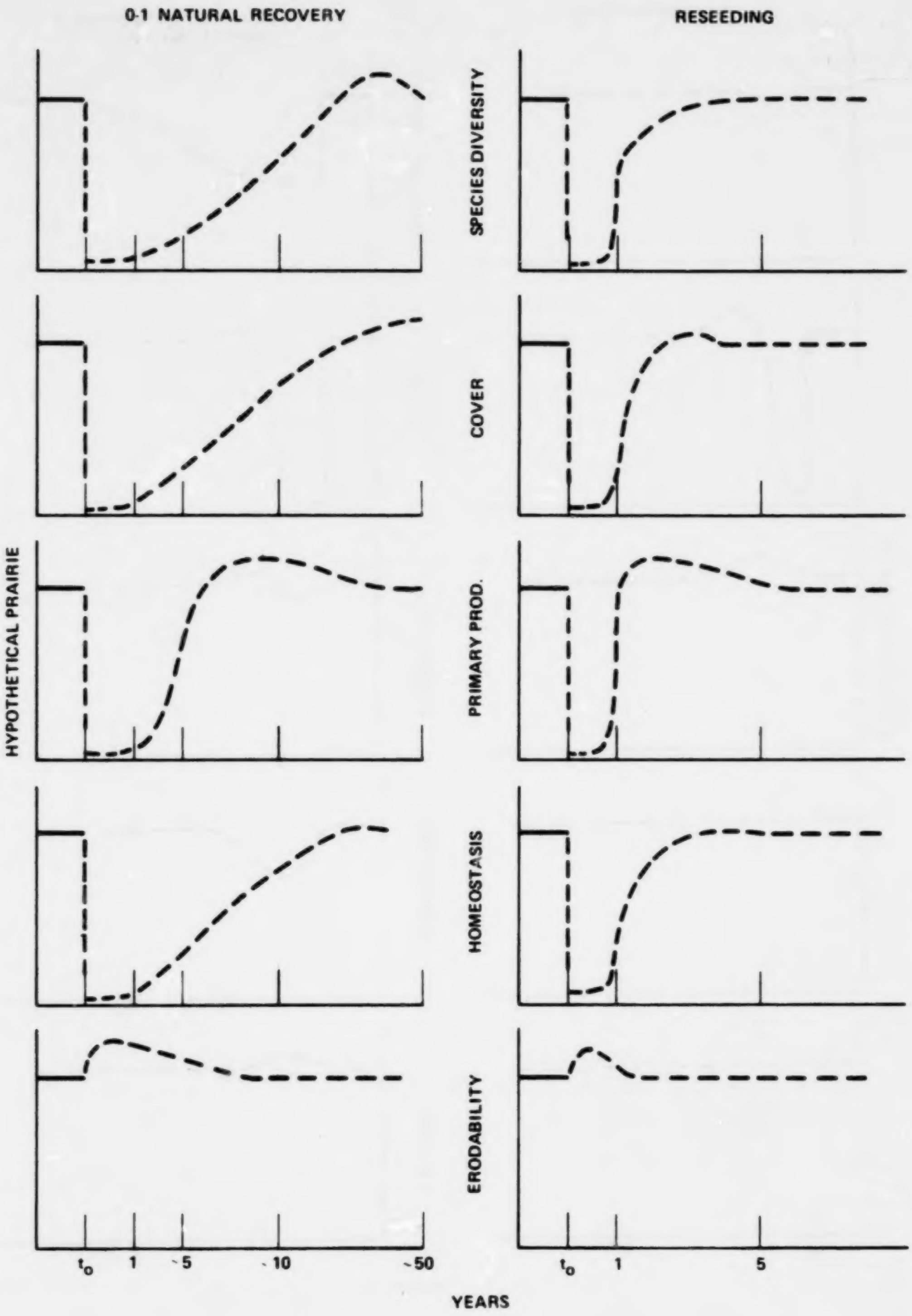

Figure 2-1. Natural recovery and recovery with reseeding of prairie.

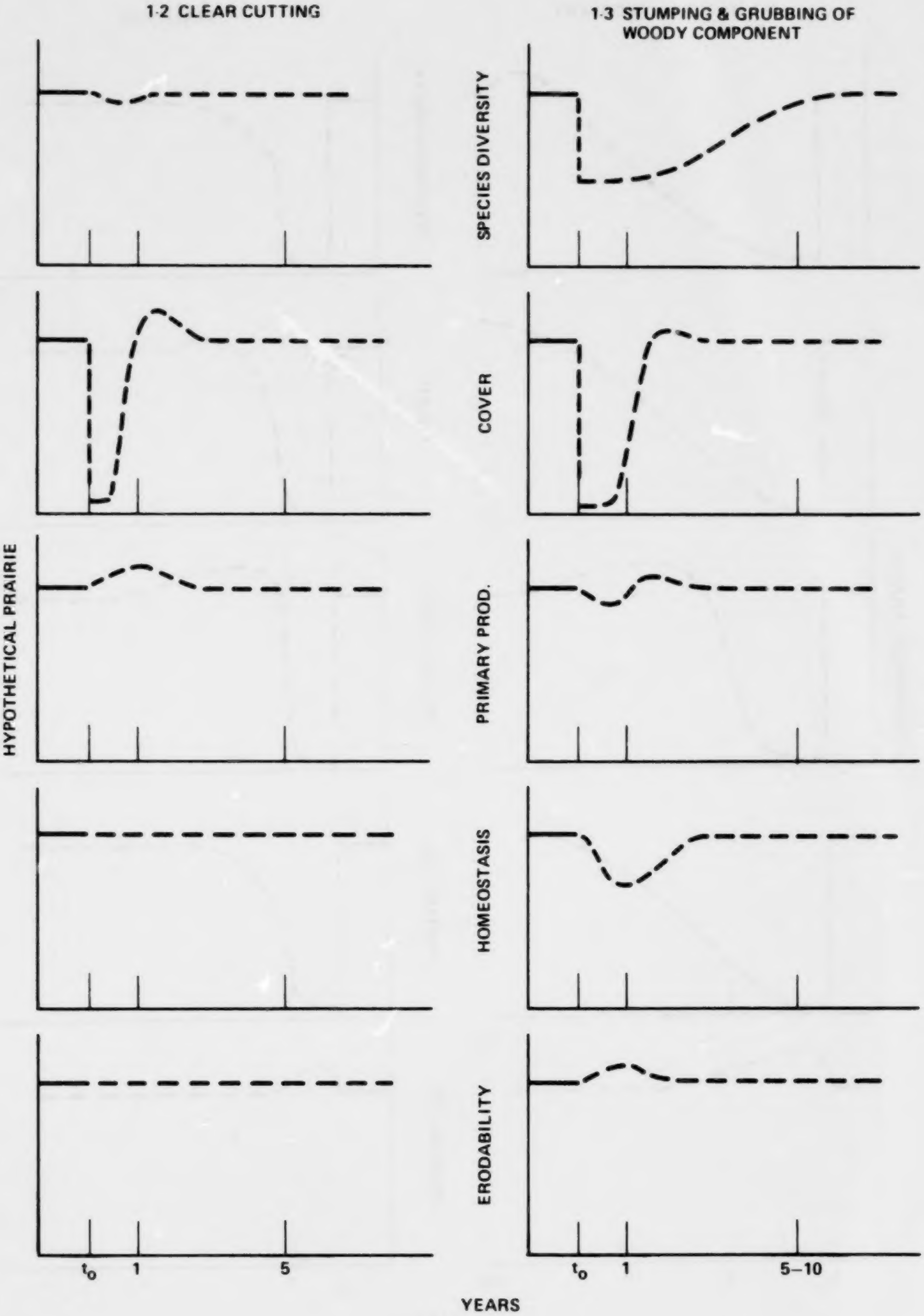

Figure 2-2. Time course of change after mowing (1-2) and stumping and grubbing (1-3) of woody component of prairie.

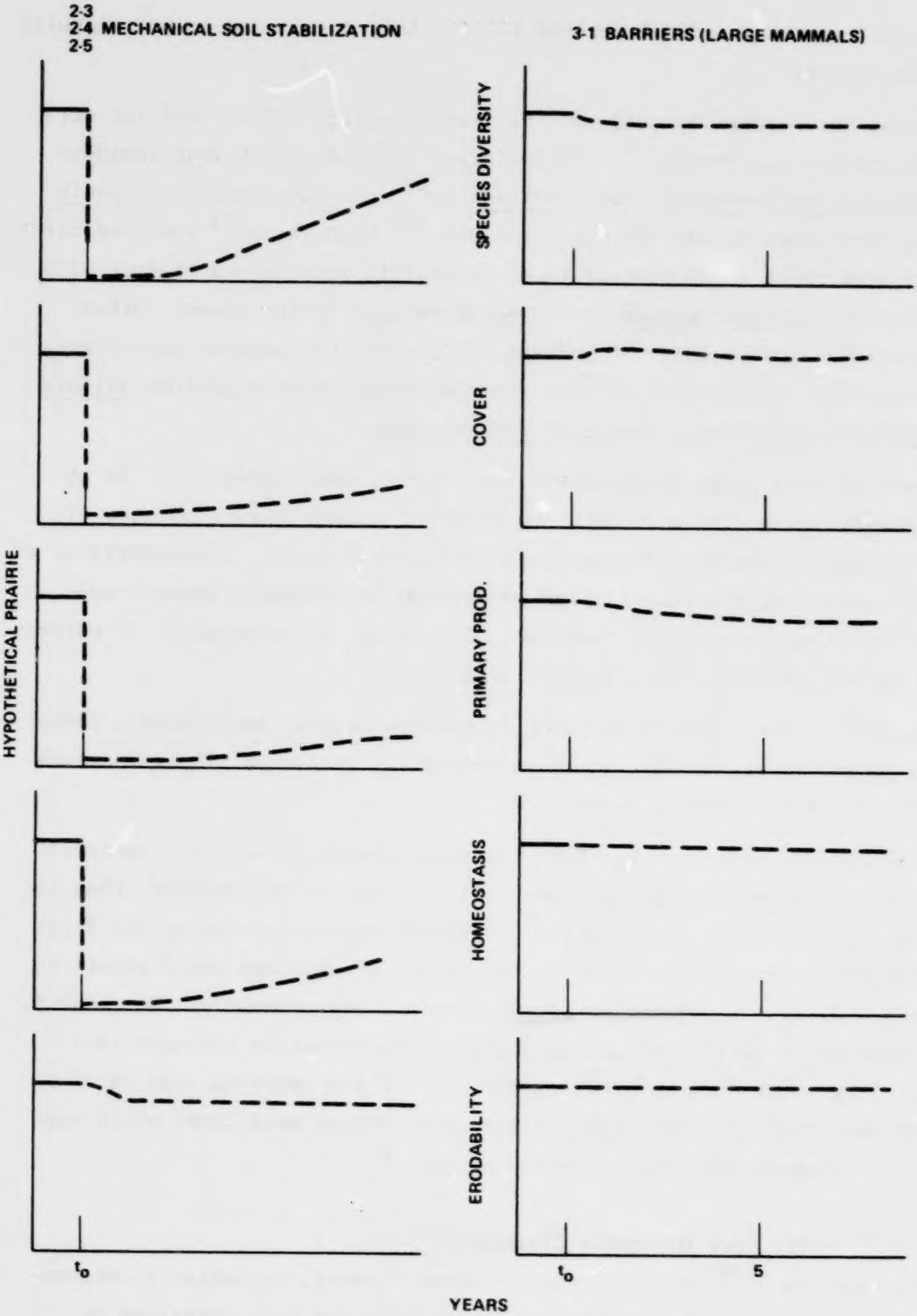

Figure 2-3. Recovery of prairie following mechanical soil stabilization and response to the erection of fencing.

2 percent, 0.7 percent, and 0.2 percent for 0.1 km^2, 1 km^2, and 10 km^2 circular plots, respectively.

In areas not reached by seeds of the climax species, first-year invaders are annual grasses and "weeds."[4] In tallgrass prairie, first-year invaders include *Ambrosia psilostachya*[27] and *Aristida* sp.[23] Russian thistle (*Salsola kali*) is a first-year invader of mixed prairie.[16] Launchbaugh[18] reported first-year basal area cover of 20 percent to 60 percent in Texas mixed prairie with the annual grass *Panicum texanum* providing 36 percent of the cover. Other annuals provided another 10 to 15 percent cover with the reminder due to non-climax perennials. First-year invaders of shortgrass prairie include *Salsola kali*, *Amaranthus retroflexus*, and *Chenopodium album*.[7]

The annual weed stage persists for more than a year, typically. In an Oklahoma old-field studied by Perino and Risser[25] a weed stage comprised of Ambrosia, Sorghum, Bromus, and Rumex persisted 2 to 3 years. Characteristic of the weed stage is the relatively large proportion of community biomass contained in the living vegetation component, 51 percent as compared to 26 percent in the tallgrass prairie climax for the area.

To summarize first-year conditions in prairie natural successions, there is little ground cover and that which is present is comprised of plants which die at the end of the growing season.

If the cleanup procedure has left the surface with a less than suitable seedbed, such as might be the case when soil is added to the surface, then it is entirely possible that no significant invasion will occur during the first year. Stabilization would be required to prevent erosion and would result in still further delays in vegetation establishment. Improvement of the seedbed, such as addition of fertilizer and mulching if precipitation averages less than about 7 cm [9] can lead to seeding success. If the imported soil is of a quality to encourage recovery, then it may also contain weed seeds which may initially out-compete the local, desired species.[9]

2.5.2.2 Fifth Year Following Cleanup--

Weaver and Bruner[41] reported that 8 "normal" years, including 3 consecutive "good" years restored a tallgrass climax which had been converted to midgrass by the drought of 1934-1936. It is assumed that 5 normal years following a particularly wet year, would operate on a similar time scale.

Under the natural revegetation of circular plots, and assuming the 2 m movement of climax species seeds suggested by Rice et al.[28] continues each year, nearly one-third of a 0.01 km^2 disturbed area would be in climax vegetation. Only about 1 percent of a 10 km^2 disturbed area would be in climax.

Areas too far from seed sources to contain climax species would, after 5 years, remain in an earlier successional stage. Osborn and Allan[23] identified 7 seral stages within a 9-year succession on an abandoned prairie dog town. The midpoint, after about 5 years, was characterized by a mixture of annual grasses (Aristida sp.) and subclimax perennial grasses (Chloris and Sporobolus). In another abandoned prairie dog town,[16] subclimax perennial grasses dominated after 7 years. Each area was a tallgrass prairie climax.

After 5 years following plowing of midgrass prairie, it too was a mixture of annual grasses (Aristida) and subclimax perennial grasses (Paspalum and Andropogon). Climax grasses had begun to appear but contributed an insignificant amount of the total cover, only 0.2 percent. Total ground cover (basal area) itself, was less than half that of the regional climax.

Thus, cleanup procedures which leave a suitable seedbed would most likely remain in subclimax grassland following 5 years of natural succession. Burial with soil could yield similar results if the quality of the soil added is similar. Reliance on natural succession on poorer quality soil material would probably result in slower rates of succession with annual grasses and forbs possibly predominating after 5 years.

2.5.2.3 Tenth Year Following Cleanup--

For each of the cleanup procedures which leaves a plowed-field-like starting point, all prairies should be in subclimax grassland after 10 years. Tallgrass prairie regions may still be dominated by midgrasses and mixed grass or shortgrass prairies may be dominated by bunchgrasses. The 9-year-old successional stage in the abandoned prairie dog town[23] was subclimax midgrasses, silver bluestem (Andropogon saccharoides) and sideoats gamma (Bouteloua *curtipendula*). Tallgrass prairie was the regional climax. *A. saccharoides* still comprised 84 percent of cover after 14 years in Texas tallgrass prairie and 31 percent after 20 years.[18] Western wheatgrass (*Agropyron smithii*), needle-and-thread (*Stipa comata*) and feather bunchgrass (*Stipa viridula*) dominated abandoned fields in western North Dakota within 10 years.[47] The authors stated that these midgrasses were characterized by low total density but that they nevertheless produced a relatively high yield of good quality forage and were valuable hay land.

Not all authors agree, however. Booth[4] stated that annual grasses still predominated after 10 years in southeastern Kansas and east-central Oklahoma.

Few differences between cleanup procedures would be discernible after 10 years of prairie succession. Prairie soils are sufficiently deep that scraping and grading, deep or shallow plowing or removal of soil up to 30 cm would leave a sufficient seedbed to produce comparable stands within a decade. If burial had been with particularly low quality soil, and no other treatments had been performed, then succession would lag sufficiently that prairies might remain in the annual grass or grass/forb stage after a decade.

2.5.2.4 Climax--

Tallgrass prairie apparently can return to climax very quickly if the disturbed area is small and climax species are nearby. Weaver and Rowland[42] reported that *Andropogon-Sporobolus-Panicum* prairie was established on a dirt road only 15 years after abandonment. Perino and Risser[25] reported a somewhat longer sere. They described a 4-stage sere starting with (1) a weed stage (*Ambrosia, Sorghum, Bromus, Rumex*) lasting 2 to 3 years, (2) an annual grass stage (*Aristida oligantha, Andropogon saccaroides*) lasting 9 to 13 years, and (3) a perennial bunchgrass stage (*Andropogon scoparius*) lasting 30 years or more. Equilibration or climax would not occur, therefore, for 40 to 50 years following disturbance. Climax was *Andropogon gerardi*, *A. scoparius* and *Panicum virgatum*.

Costello[7] described succession in northeastern Colorado mixed grass prairie as (1) an annual forb stage (*Salsola kali*, *Amaranthus retroflexus*, *Chenopodium album*) lasting 2 to 5 years, (2) a forb stage lasting 3 to 6 years, (3) a short-lived perennial grass stage (*Schedonnardus paniculatus*, *Hordeum* jubatum, Sporobolus cryptandrus) lasting 4 to 10 years and (4) an Aristida stage (Aristida longiseta and A. purpurea) lasting 10 to 20 years. Transition to climax was estimated to take another 10 to 20 years. Thus, the sere could be as short as 15 to as long as 60 years with drought cycles retarding succession and wet years accelerating succession.

Launchbaugh[18] described the sere of the San Antonio Prairie in Texas. Following cultivation, an annual grass stage was established the first year with Panicum texanum being the dominant. Annuals gave 82 percent to 85 percent of the cover and subclimax perennials gave the rest. No climax species were present the first year and cover (basal area) was low 20 to 60 percent. After 5 years, annuals (Aristida supp.) contributed only 46 percent of the cover and subclimax perennials had increased to 47 percent (Paspalum and Andropogon). Climax species were represented (0.2%) and basal area had increased to 2.1 percent. After 14 years, annuals were only 7.2 percent of the plants present and subclimax perennials (Andropogon saccharoides) had increased to 84 percent. Climax species (Sporobolus and Stipa) had increased to 5 percent and basal area had increased to 2.7 percent. After 20 years, annuals were 3.5 percent and subclimax perennials 31 percent. Climax species had increased to 60 percent, most of which were Andropogon scoparius. Basal area was up to 3.3 percent. No estimate of the additional time required to reach climax was given. A climax community was described, however, and the climax species (Andropogon and Bouteloua) were 94 percent of the vegetation and basal area was up to 4.8 percent. Both annuals and subclimax perennials were represented in the climax community, 1.3 percent and 1.1 percent respectively. Whitman, et al.,[47] estimated 40 to 60 years or more were required for succession to climax in North Dakota mixed grass prairie.

A shortgrass prairie in Colorado was still in the annual grass (Aristida) stage 21 years after abandonment. Shantz[35] estimated to reach climax in shortgrass (Bouteloua-Buchloe) prairie it would take 20 to 50 years following plowing.

2.6 QUANTITATIVE ASSESSMENT OF CLEANUP IMPACTS

The boundless forests of the eastern U.S. are matched in diversity by the limitless span of grasslands reaching west up the Rockies from the eastern forest's edge. On high western plains removal of 40 cm of soil (2-2) leaves an alkaline, frequently saline excavation in North Dakota, with 300 to 500 mm annual precipitation for short and mixed grasses to revegetate the Colorado plains on intermittantly exposed parent material (A through upper B_3 horizons removed). On the excavated eastern prairie there may be no noticeable reduction in soil profile properties, plus 1800 mm of precipitation falls under which tall grass revegetation will progress. Assessments of cleanup impacts and subsequent time to recover productivity are reduced to generalities that address this range of site diversity. Over their summer rain, wind, and unshaded range, the grasses did maintain, with rare exceptions, an almost permanently dry subsoil below the root zone. This land has been appropriated throughout for agriculture. Recovery is treated in this chapter in the context of principles governing an unmanaged ecosystem; agriculture is examined in Chapter 8.

2.6.1 Impact Assessment

Mowing prairies (1-2) has no long-term effect. The slight increase in impact rating with increased area relates to reduced food availability to herbivores and reduced cover for wildlife. Scraping and grading (1-3), and shallow plowing (1-5) have limited impact when localized but represent an extension of the trend mentioned for mowing. Deep plowing (1-6) requires reinvasion of species from outside of the disturbed area, hence the greater increase in impact level as area increases. Soil burial (1-7, 1-8) requires plant reinvasion and also has greater impact as area increases. But since the transported soil added is assumed to provide a seedbed inferior to the soil covered up, impact is greater than for other treatments requiring reinvasion, such as deep plowing. Soil removal (2-1, 2-2) requires reinvasion also and since deep plowing may leave seeds to germinate, the removal of seeds with the soil results in a greater impact. One intuitively feels that removal of up to 40 cm of topsoil should be a greater impact than removal of 10 cm. In deep prairie soils, however, it is not entirely clear that it is. Hence, there is just a slight increase in impact level. Barriers to exclude people would have essentially no impact on prairies. Trees might invade the eastern prairie remnants if man-made fires were excluded, but that is not considered a negative impact. Exclusion of animals by barriers (3-2, 3-3) should have little long-term impact, since the grasses to support grazers would remain. Animal populations are expected to quickly recover when permitted back in. Paving represents the ultimate loss with the area paved being the only qualifier.

2.6.2 Recovery Assessment

Factors which affect the rate of recovery in prairies have been discussed in Sections IV and V. Because of the interactions of those factors, quantification of the time required for recovery (Table 2-1) cannot be precise. For example, scraping and grading (1-4) of grassland may not result in death of significant numbers of grass plants and recovery may be extremely rapid, two or three years. However, the potential exists for all of the grass plants to be killed with the subsequent recovery taking as long as recovery from plowing, up to 60 years. Nor can a superficially more-destructive, cleanup procedure be counted upon to require longer recovery times than a less destructive one; hence, the overlapping ranges in time required to return to full productivity.

Impact is also expected to increase as area increases, but with the exception of more rapid revegetation of smaller areas, no clear relationship between area and time-to-climax is apparent. Succession on homogeneously barren areas of up to 10 km^2 has not been documented and extrapolation from smaller areas is dangerous. The dividing point in time to recover seems to be between areas smaller than 0.1 km^2 and larger than 0.01 km^2 where area effects become discontinuous. The discontinuities come with disturbance of the seedbed and the general east to west decline in annual precipitation. The impacts increase and the time to recover climax increases along the east to west precipitation gradient.

Recovery from toxic constituents in chemical stabilizers (1-1) used for temporary "paste down" is expected in two or three years. Mowing (1-2) of prairie leaves minimum impact and recovery would be expected within the next growing season.

Table 2-1. Predicted recovery index in prairie for cleanup treatments (see Appendix B).

Treatment	Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	0	0	0	0	Effects gone first or second year following manual cleanup.
1-1 Chemical Stabilization	0	0	0	0	Effects gone first or second year.
1-2 Remove Vegetation by Clear Cutting	0	0	0	0	
1-3 Remove Stumps and Grub Roots	---	---	---	---	Not feasible here
1-4 Surface Scraping and Grading (<5 cm)	1	2	2	2	
1-5 Shallow Plowing (<10 cm)	1	4	4	4	
1-6 Deep Plowing (10 to 40 cm)	2	4	4	4	
1-7 Soil Cover (<25 cm)	4	5	5	5	
1-8 Soil Burial (25 to 100 cm)	4	5	5	5	
2-1 Remove Plow Layer Soil (10 cm)	2	4	4	4	
2-2 Remove Shallow Root Zone Soil (<40 cm)	4	5	5	5	
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	2	3	3	3	
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	3	5	5	5	
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	4	5	5	5	
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	1	2	2	2	
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	2	4	4	4	
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	4	5	5	5	
3-1 Barriers to Exclude People	0	0	0	0	
3-2 Barriers to Exclude Large Animals	0	0	0	0	
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	
4-1 Asphalt Hard-Surface Stabilization	+	+	*	*	
4-2 Concrete Hard-Surface Stabilization	+	+	*	*	
5-0 Sewage Sludge Application	*	*	*	*	
6-1 Washing (<3 mm)	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	
7-0 Soil Amendments Added	*	*	*	*	

*Outside scope of work.

+Not recommended for this land type.

The index numbers show the approximate number of transition stages to reach pre-cleanup conditions. Appparent climax in ~80 years; methods of indexing in Appendix B, Tables B-2, B-5, B-6 and the related text.

In considering treatments 1-4 through 2-2, those procedures which left conditions similar to post-agricultural seedbeds (1-4, 1-5, 1-6, 2-1) were considered to have "typical" successions with the expected upper limit equivalent for all treatments and the expected lower limit being varied according to perceived potential for minimal impact. Those which were considered to yield impact in excess of agriculture (1-7, 1-8, 2-2) were assigned potentially longer recovery periods.

The various mechanical and chemical stabilizers used following cleanup (2-3 through 2-8) may have significant impacts on early succession but are not thought to be particularly significant in determining the ultimate length of the sere. That is, the maximum time to recovery may result from more basic factors such as soil erosion and minimums in precipitation cycles. The initial effects of stabilization may become lost before climax vegetation is established. This is not to recommend for or against stabilization. Stabilization decisions should be made on a case-specific basis and based on local range management, soil science, and road construction expertise and experience.

Treatments 3-1 and 3-2 are essentially "no action" options and, consequently, have no recovery time. This does not imply that there will be no effect on ecosystems, however (see Section 2.4).

Hard-surface stabilization (4-1, 4-2) represents the greatest potential impact with the longest recovery times even on the smaller areas to 0.10 km^2. Its use is not recommended, therefore, and it is classed as "prohibited" on prairie.

In general, the smaller the area and the less radical the cleanup treatment the quicker the recovery becomes. The variations in soils, climate, and local mixtures of plant and animal species make the return to full productivity a highly site-specific process.

2.7 CONCLUSIONS

Among the several "preferred" cleanup treatments, in most instances, the "no action" options (3-1, 3-2) are first choice. Their advantage is in allowing time for careful consideration of possible courses of action with respect to specific units of landscape that are contaminated. Presumably, it would be possible to conduct field-plot trials to determine what combination of alternatives would be the most desirable decontamination procedures. Whether the barriers should exclude only people or all animals cannot be completely defined as a generality. As long as food chains leading to man are isolated from the contamination, there should be no concern about non-game wildlife crossing the barriers. Mowing (1-2) represents the second level of ecological preference.

It is recognized that health and safety considerations may require immediate and effective action. In such cases, preservation of a seedbed through plowing (1-5, 1-6) is preferred, especially if the area can be reseeded instead of relying on natural recovery. Full recovery with reseeding may require fewer than five years as opposed to up to sixty to eighty years for bare ground after soil removal.

Soil removal (2-1, 2-2) or deep soil cover (1-7, 1-8) should be considered last-resort options, when followed by reclamation to reduce recovery times. The choice between these latter options should be made by local professionals in soils, range management, and highway construction.

The "prohibited" cleanup treatments in prairie are the variations of hard-surface stabilization, with asphalt (4-1) or with concrete (4-2). The 30-year delays caused by their natural breakup require that they be removed bodily eventually and reclamation procedures instituted. Other contamination cleanup methods are available which are only moderately damaging to this land type.

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CHAPTER 3
DECIDUOUS FOREST

3.1 OVERVIEW

Temperate deciduous forest is a vegetation type in which broad-leaved trees, the dominant growth form, exhibit an annual cycle of shedding their leaves and becoming dormant as day length decreases and developing new leaves and becoming photosynthetically active as day length increases. Deciduous forest is found in parts of some 33 states in the eastern half of the United States, including the flood-plain forests which extend, finger-like, deeply into the prairies.[26] Deciduous forest is bordered by prairie on its western edge, which extends from Canada to Texas. The border (ecotone) between deciduous forest and prairie is typically savanna, grassland with scattered trees, comprised of species contributed from each of the two major vegetations (e.g. Andropogon-Quercus). Moisture limits the western extension of deciduous forest. The northern boundary is with the Canadian boreal forest with a broad ecotone of deciduous trees and conifers extending across the great lakes region into England. The eastern and southern borders are effectively the Atlantic Ocean and Gulf of Mexico, respectively.

Regionally, precipitation ranges from approximately 76 cm to 152 cm, annually, and is evenly distributed throughout the year.[36] Locally, such factors as soil type, aspect, and topography may exert a greater influence on forest type or distribution than gross precipitation.[8]

The deciduous forest of the eastern United States is by no means homogeneous. Kuchler[26] mapped 14 major forest associations, Braun[8] recognized nine. A great deal of variability is contained within either system under native, undisturbed conditions. Anthropogenic (man-made) changes in vegetation have greatly increased the variability over native conditions.

3.1.1 Mixed Mesophytic Forest

Mixed mesophytic forest is the prevalent forest of the unglaciated Appalachian Plateau Region of Pennsylvania, West Virginia, Ohio, Kentucky and Tennessee. Diversity characterizes the mixed mesophytic forest, both in flora and fauna. The floral dominance is shared by maple (*Acer saccharum*), buckeye (*Aesculus octandra*), beech (*Fagus grandifolia*), yellow poplar (*Lirodendron tulipifera*), white oak (*Quercus alba*), northern red oak (*Q. rubra*) and basswood (*Tilia heterophyla*). Kuchler[26] listed 26 other tree species as major components.

3.1.2 Oak-Hickory Forests

A wide-spread forest type in the central United States, oak-hickory forest occurs in the drier regions of the deciduous forest biome. Lying west of the mixed mesophytic forests, it extends in a discontinuous distribution from Michigan to Alabama in the east, to Oklahoma and Texas to the southwest and as lowland forest into Nebraska and Iowa. Dominant trees are various oaks (*Querus alba*, *Q. rubra*, *Q. velutina*) and hickories (*Carya cordiformis*, *C. ovata*) with American elm (*Ulmus americana*), basswood (*Tilia americana*), black walnut (*Juglans nigra*) and white ash (*Fraxinus americana*) being important components.

3.1.3 Appalachian Oak-Chestnut Forest

Appalachian oak-chestnut forest includes the Ridge and Valley Province and the Blue Ridge Province in the south and widens to include much of Ohio, Pennsylvania and New Jersey, and the coastal plain north to southern Maine. Since the loss of American chestnut (*Castanea dentata*) to an introduced fungal disease, the dominants are white oak (*Quercus alba*) and northern red oak (*Q. rubra*). Maples (*Acer rubrum*, *A. saccharum*) and hickories (*Carya cordiformis*, *C. glabra*, *C. tomentosa*) are important, as are black birch (*Betula lenta*), beech (*Fagus grandifolia*) and yellow poplar (*Lidrodendron tulipifera*).

3.1.4 Oak-Hickory-Pine Forest

Characteristic of the piedmont, this forest type extends west to Texas. Dominants include various hickories (*Carya* spp.), shortleaf pine (*Pinus echinata*), loblolly pine (*Pinus taeda*), white oak (*Quercus alba*) and post oak (*Q. stellata*). A rich forest (Kuchler[26] listed 19 other components), the climatic climax is probably oak-hickory[8] but much of the region has been dominated by second-growth pine forests since pre-settlement times. The erodable, red and yellow clay soils of the region are well-known.

3.1.5 Southern Mixed Forest

This forest type occupies the coastal plain from South Carolina to Louisiana and into Texas. Much of the region is covered with pine, especially loblolly (*Pinus taeda*) which some authors[36] have considered to be an edaphic (soil derived) climax. Experimental data have shown, however, that the pines yield to hardwoods when fire is excluded. Kuchler[26] listed the dominants as beech (*Fagus grandifolia*), sweet gum (*Liquidambar styraciflua*), magnolia (*Magnolia grandiflora*), slash pine (*Pinus elliottii*), loblolly pine (*P. taeda*), white oak (*Quercus alba*) and laural oak (*Q. laurifolia*). Braun[8] considered the forest to be transitional to subtropical evergreen forest with northern species dropping out in central Florida and being replaced with more southerly species.

3.1.6 Beech-Maple Forest

The beech-maple forest is found from Indiana to New York, including parts of Michigan. Mature beech-maple forest presents almost a park-like appearance with large trees forming a light-extinguishing canopy such that little undergrowth can survive. Beech (*Faus grandifolia*) and sugar maple (*Acer saccharum*) are the dominants with Ohio buckeye (*Aesculus glabra*), shagbark hickory (*Carya ovata*), white ash (*Fraxinus americana*), black walnut (*juglans nigra*), yellow poplar (*lirodendron tulipifera*), wild black cherry (*Prunus serotina*), red oak (*Quercus rubra*), basswood (*Tilia americana*), American elm (*Ulmus americana*), and slippery elm (*U. rubra*) being locally important.

3.1.7 Maple-Basswood Forest

Maple-basswood is a limited forest type in northern Illinois, northeastern Iowa, Wisconsin, and Minnesota. Sugar maple (*Acer saccharum*) and basswood (*Tilia americana*) are the dominants with northern red oak (*Quercus rubra*) usually being present. Other important species include box elder (*Acer negundo*), bitternut hickory (*Carya cordiformis*), red ash (*Fraxinus pennsylvanica*), Hop-hornbeam (*Ostrya virginiana*), bur oak (*Quercus macrocarpa*), American elm (*Ulmus americana*) and slippery elm (*U. rubra*).

3.1.8 Hemlock-Hardwood Forest

An ecotone and not a distinct forest type, the hemlock-hardwood forest stretches from Wisconsin to Maine with islands at higher elevations of the Appalachians south to Tennessee and North Carolina. It merits consideration on size alone. The dominant trees are beech (Fagus grandifolia), sugar maple (Acer saccharum), yellow birch (Betula allegheniensis) and hemlock (Tsuga canadensis).

The eight forest types described represent what is considered to be the potential vegetation of significantly large portions of their regions. None of them was ever homogeneous over their ranges and that is certainly true today. The vegetation of a region has always been a dynamic concept with climate, fire, and anthropogenic influences producing continuous change[14].

Vegetational development on a particular site has varied with the influences producing change[14] and as new perturbations occur, new developmental sequences and end points may result[47]. Nevertheless, ecosystem development, either on new substrate (primary succession) or recovery following disturbance (secondary succession), follows a course which is highly predictable in generality, if not in specific cases. The generalities offer a point of reference and will be discussed first.

3.1.9 Theoretical Considerations

As a forest ecosystem developes, changes take place which convert a community comprised primarily of small, short-lived, opportunistic species having little effect on their environment to a community comprised of organisms which tend to be larger, long lived, and which often exert great control over their own environment. Some of those trends were summarized by Odum[35] from which Table 3-1 is adapted.

A great deal of evidence has been accumulated which supports the generalizations in Table 3-1. That biomass accumulates is obvious to anyone who compares a forest with an abandoned field. Whittaker[46] described a succession on Long Island, New York (oak-hickory-pine in the system used here) in which biomass was approximately 1 kg/m^2 in the earliest stages and increased to between 30 and 40 kg/m^2 in the mature forest. Biomass increased sigmoidally (Figure 3-2) with the result that increasing metabolic demands reduced the

Table 3-1. Parameter trends during deciduous forest succession (adapted from Odum[35]).*

ECOSYSTEM ATTRIBUTE	EARLY SUCCESSION	MATURE FOREST
Biomass	low	high
Gross production/respiration	high	low
Gross production/biomass	high	low
Net exosystem production (potential yield)	high	low
Food chains	simple linear, mainly grazing	complex, interconnected, detritus-based
Species diversity	low	high
Stratification	little	much
Size of dominants	small	large
Life cycles	short, simple	long, complex
Niche relations	Broad, opportunistic	narrow, specialized
Nutrient cycling	open	closed
Detritus	little, unimportant	important
Overall homeostasis	poorly developed	well-developed
Stability	low	high

*Terms in this table that are not in Glossary should follow definitions given by Odum.[36]

energy available for incorporation into new biomass. Consequently, yield declines with ecosystem development.

With development in forest ecosystems, an organic layer accumulates on the forest floor. Prior to the accumulation of this detritus, animal food-chains are limited to those organisms which can consume the living vegetation (herbivores and their predatozs). As the detritus increases, a complex of microflora and small cryptozoa (literally "hidden animals") begin to exploit it as a resource base. In a beech forest in Denmark, Bornebusch[7] found an average of 4424 cryptozoa/m^2 with a biomass of 37.8 g.

There is consensus that species diversity increases during succession although mature ecosystems tend to be less diverse than younger, transitional stages. Odum[36] gave an example of a forest which attained maximum diversity at an age of almost 160 years with diversity declining beyond that. Whittaker[46] gave as an example a forest which attained maximum diversity quickly, in about 8-10 years, and declined gradually as the ecosystem developed. It is accepted that maximum diversity is attained during the transition from one more-or-less discrete successional stage to another when species belonging to each state coexist in the same area. Consequently, in the example given by Odum[36] maximum diversity apparently occurred during the transition to a mature forest, the usual case, and in the example given by Whittaker[46] maximum diversity occurred during the transition from the herb to shrub stages.

Stratification, layering in the forest, is a correlate of species diversity. The generalized sequence of herb to shrub to tree dominance is, in effect, the adding of layers which add species to the community. Bird species reflect the effect of increasing stratification perhaps most clearly. Johnston and Odum[21] reported two breeding bird species in a three-year-old field having a grass-forb dominance, 13 species for the local oak-hickory-pine climax. The size of dominants and their life history complexity also are correlated with increased diversity and stratification as succession proceeds to climax. Bazzaz[3] reported that _Solanum carolinense_, _Ambrosia artemisiifolia_, and _Digitaria sanguinales_, all low-growing annuals (plants which complete their life cycles in one season), were established in a cornfield before the first winter after abandonment. Climax for the area was oak-hickory with _Quercus velutina_ being the major dominant.

Early successional stages are said to have open nutrient cycles in which the nutrient elements are primarily extrabiotic (outside of organisms and their products). Mature stages are said to have closed cycles in which detritus serves as a critical link between uptake and loss of nutrients from vegetation. Vitousek and Reiners[45] examined this hypothesis and found that for elements which have atmospheric inputs to ecosystems, outputs from the ecosystem in the form of stream discharges were low during the rapid growth of early succession and increased with maturity to where element input and output were approximately equal. Thus, it may be concluded that uptake in mature forests is in equilibrium with release of elements from organic matter. Thus, constancy characterizes mature ecosystems, and represents a measure of stability and homeostatic control.

Two categories of perturbations have occurred during the history of deciduous forests which may yield insight into the impacts of spill cleanup. Natural perturbations and anthropogenic (man-induced) perturbations are not always distinct from each other, however. An example of where they overlap is fire. Fires have occurred naturally throughout the history of deciduous forests[17] but, observing the changes that fire brought to deciduous forest ecosystems or their utility as hunting tools, the American Indians would deliberately set fires.[12] Thus, inclusion of fire as a "natural" perturbation is somewhat arbitrary.

3.2 NATURAL PERTURBATIONS

3.2.1 Fire

The role of fires in ecosystems has recently been summarized.[24] Lightning has been the primary source of naturally occurring fires although man has been setting fires in North America for an estimated 20,000 years.[23] The primary difference between natural or lightning fires and set fires is the seasonality. Electrical storms are essentially summertime phenomena, occurring when overall combustibility is typically low. Set fires can occur at any time and thus are potentially more destructive. It is probable that the grass fields of central Kentucky described by Clark[12] were maintained by frequent fires set by Indians.

Early succession following complete forest removal by fire in Finland[44] was qualitatively similar to succession following other massive perturbations.

The pioneer invaders were reselected, annual species with windborne seeds, such as dandelion (*Taraxacum officinale*) hawksweed (*Hieracium* spp.), and fireweed (*Chamaenerion angustifolium*). Other early invaders, such as raspberry (*Rubus idaeus*), were carried by birds. An herb stage was evident after 3 years and grasses were dominant by the sixth year.

Henry and Swan[17] reconstructed a 300-year sere (successional sequence) in New Hampshire from evidence contained in the soil and trees growing on the site. From charcoal and partially burned wood found in soil and from the ages of the oldest trees in the forest, they concluded that a massive fire had destroyed the forest in about 1665. They were able to identify eastern white pine (*Pinus strobus*), white oak (*Quercus alba*), hemlock (*Tsuga canadensis*), spruce (*Picea* sp.), red maple (*Acer rubrum*), and aspen (*Populus* sp.) as components of the destroyed forest, species found in the region today.[26] Herbaceous or short-lived early invaders left no records, but the ages of extant trees allowed them to reconstruct the succession of tree species. White pine (*Pinus strobus*) was the first tree invader, coming in between 1665 and 1687 and producing a distinct pine forest stage. Hemlock (*Tsuga canadensis*) invaded between 1684 and 1780, paper birch (*Betula papyrifera*) in 1742, 1770 and 1795, red oak (*Quercus rubra*) between 1790 and 1860 and beech (*Fagus grandifolia*) began entering slowly in 1815. Thus, it took 150 years for the dominants of the new climax forest to appear and possibly another 50 to 100 years for them to establish dominance. Consequently, in New Hampshire, it may take up to 250 years for a mature forest to reestablish itself following a massive perturbation, such as complete consumption by fire. Furthermore, minor perturbations, such as wind-felling of trees during some 250 years, can open patches of forest at different successional stages, and consequently different environmental conditions, which permits the invasion of still further tree species which will determine the ultimate composition of the forest. Therefore, specific predictions cannot be made about the ultimate consequences of a particular gross perturbation.

Other fires, which remove the understory of forests without seriously injuring the dominant trees, have no correlate among the proposed clean-up procedures and will not be treated.

3.2.2 Primary Successions

Primary successions occur where no ecosystem has previously existed, such as on newly-created volcanic land. Land masses within the eastern deciduous forest region have been remarkably stable for thousands of years and, consequently, primary successions are poorly understood. Surface mining using overburden for reclamation, may produce a substrate which can lead to essentially a primary succession. Costly mandatory rehabilitation bonds, for contouring spoil banks to avoid instability and slope failure, exert economic pressure for "natural recovery." Information on the probable years for primary succession, on surface-mine spoil banks, becomes vital to predict the years to complete rehabilitation.

A case history of primary succession was developed by Morrison and Yarranton[30,31] for sand dunes. They have identified three stages in primary succession. The first stage or colonizing stage lasts up to 1600 years and is characterized by beachgrass (Ammophilia breviligulata), balsam poplar (Populus balsamifera), willow (Salix glaucophylloides), and sand cherry (Prunus pumila). The colonizing stage is followed by a transition stage lasting another 1300 years and characterized by scattered trees without canopy closure. The typical species are hybrids of red and black oaks (Quercus rubra x velutina), fragrant sumac (Rhus aromatica), choke cherry (Prunus virginiana), a sedge (Carex languinosa) and snowberry (Symphoricarpos racemosus). That is followed by a persistent stage lasting at least 1900 years and comprised of white oak (Quercus alba), New Jersey tea (Ceanothus americanus), black cherry (Prunus serotina) and teaberry (Gaultheria procumbens).

The number of species apparently increases to a stability point approximately 2000 years after the dune is formed while frequency continues to increase throughout the 4800 years, which is too long to wait.

3.3 MAN-MADE PERTURBATIONS

3.3.1 Surface Mining

Although not nearly as extensive as clearing for agriculture, surface mining represents a massive perturbation which is both highly visible and difficult to ameliorate. The mine spoil which typically finds its way to the surface is analogous to a new land surface and, consequently, natural successions on mine spoil somewhat resembles primary successions. Since no 4800-year-old mine spoils have been identified, there is no evidence that the two are directly parallel. A further complication is the acidity problem shared by the central and Appalachian coal fields. In these areas, iron disulfide is exposed to air, oxidizes and produces sulfuric acid. Spoil pH is often too low to support plant life and the low pH tends to increase the solubility of a number of metal ions which reach toxic levels. None of the proposed cleanup procedures is likely to expose appreciable quantities of these acid-forming disulfides. Once the pH of surface mine spoils is adjusted, the plant substrate is possibly quite similar to the product of cleanups, particularly on shallow soils. Therefore, examination of the revegetation history of mine spoils may provide a model of the consequences of some cleanup procedures.

Surface mining in the eastern United States, especially in the rugged topography of Appalachia, has created problems of water runoff, erosion, and sedimentation which have led to extensive studies and actions directed toward stabilizing spoil surfaces through soil amendments and revegetation. Consequently, there exists at least some data both on natural revegetation and reclamation. In general, low pH inhibits both reclamation and natural recovery. If pH is not limiting, planting can greatly accelerate early recovery. One study estimated that replanted spoil was as much as 10 years ahead of untreated spoils after only 3 years.[18]

Untreated spoil often does revegetate naturally, however. One of the earliest reports of natural revegetation was by McDougall[29] who reported on revegetation of surface-mined bottomlands in Illinois. He concluded that proximity to a seed source was an overriding factor in the invasion rate of species. He described a sere which began with annual weeds, such as knotweeds (Polygonum aviculare and P. persicaria) with occasionally barnyard grass (Echinochloa crusgalli) and giant ragweed (Ambrosia trifida) in furrows. The drier ridges contained sweet clover (Melilotus alba), aster (Aster ericodes), sunflower (Helianthus hirsutus and H. decapetalus), ragweed (Ambrosia artemisiifolia), evening primrose (Oenothera biennis), black mustard (Brassica nigra) and prickley lettuce (Lactuca scanola). Pioneer woody species included willow (alix nigra) and cottonwood (Populus deltoides), if a seed source were available. They were followed by seedlings of the forest-stage species:

silver maple (*Acer saccharinum*), elm (*Ulmus americana*) and sycamore (*Platanus occidentalis*). He stated that a 25-year-old strip mine was covered with "well-established bottomland forest."

Croxton[13] reported on revegetation of strip-mined lands in the same region of Illinois and found evidence of the variability of results which have come to characterize such areas. He attributed the rapid recovery of the site studied earlier by McDougall to the deposition of river alluvium over the spoil and the creation of unusually favorable conditions. The sere he reported was essentially the same as that reported by McDougall, allowing for availability of various weed seeds. He indicated that recovery within 25 years was unusually rapid and that areas with pH below 4.5 failed to revegetate. He noted that the old-field shrub stage of succession, which is characteristic of deciduous forests, was poorly represented on mine spoil.

A distinct shrub stage was reported on mine spoil in southern Indiana.[11] Beginning approximately 7 years after abandonment of the spoils, the stage contained sumac (*Rhus* sp.), honeysuckle (*Lonicera japonica*), trumpet vine (*Campsis radicans*) and poison ivy (*Rhus radicans*). Included in the shrub stage were saplings of cottonwood (*Populus deltoides*), river birch (*Betula nigra*), persimmon (*Diospyros virginiana*), sycamore (*Platanus occidentalis*), sassafras (*Sassafras albidum*), slippery elm (*Ulmus rubra*), black cherry (*Prunus serotina*), flowering dogwood (*Cornus florida*) and shingle oak (*Quercus imbricaria*). By 11 years after abandonment, a tree layer had developed and by 21 years pin oak (*Quercus palustris*) and persimmon were the dominant species.

The conclusions to be drawn from these studies of early succession on strip-mine spoils are that natural revegetation can occur if soil conditions permit and that the rate and pattern of recovery is highly variable. The variability is primarily the result of the complexity of the plant growth medium resulting from mining and the variability of the seed source in the surrounding area.[40]

Revegetation of strip mine spoil has emphasized establishment of ground cover and the prevention of erosion. Species planted, such as sericea lespedeza, have been selected for their ability to quickly establish ground cover with the expectation that they will eventually be replaced by natural invasions of local species. For the most part, workers have been satisfied with achieving their primary objective. Long-term studies which seek to evaluate the return of such disturbed lands to pre-mining ecosystems are virtually nonexistent, although "full-growth" of "high-grade" forests has been achieved within 50 to 70 years.[1]

3.3.2 Post-Agricultural Successions

Secondary succession following the abandonment of agricultural land is the best-known example of ecosystem development in deciduous forests. Clearing of unproductive land, changing markets, and loss of fertility has led to abandonment of land throughout the deciduous forest. That abandonment began almost as soon as settlement began and continues into the present. Consequently, virtually all aspects of succession have received at least some study. For convenience, a regional approach will be taken.

3.3.2.1 Southeastern States--

Succession on the Georgia piedmont has been studied by Nicholson and Monk[32,33] who identified 5 major stages. Their "early forb stage" occupied the first 10 years following abandonment and was dominated by perennial grasses (*Andropogon scoparius*, *Aristida purpurascens*, *Eragrostis* sp.) and forbs (*Allium vineale*, *Erigeron canadensis*, *Haplopappus devaricatus*, *Cassia nictitans*, *Heterotheca subaxillaris*, *Aster pilosus*, *Solidago* sp., *Lespedeza* sp.). *Chickasaw* plum (*Prunus angustifolia*) and brambles (*Rubus* spp.) formed a shrub layer along with tree seedlings (*Pinus taeda*, *P. echinata*, *Diospyros virginiana*, *Celtis occidentalis*, *Rhus copallina*) and vines (*Lonicera japonica*, *Smilax bona-nox*, *Wisteria sinensis*, *Campsis radicans*). This is followed by what they called a "broomsedge stage" in which *Andropogon scoparius* increases its cover and community richness declines. The broomsedge stage lasted from the tenth to the twentieth year following abandoment. The old-field shrub stage replaced the broomsedge stage and persisted up to approximately 30 years after abandonment. Loblolly pine (*Pinus taeda*) and sweet gum (*Liquidambar styraciflua*) increase as shading, soil moisture and soil organic matter increase. Species richness increases in all strata except the herb layer, which declines due to shading and litter accumulation. The end of the stage is identified by canopy closure (approximately 30 years) and the reduction of the herb stratum to about percent of the open-field level.

Canopy closure* signals the start of the pine stage in which loblolly pine is the dominant. The stage lasts approximately 70 years (30 to 100 years post-abandonment) and there is a slight decline in total above-ground biomass for the first 60 years. Woody species increase in the understory as broad-leaved deciduous species invade. Maximum richness occurs as the species from early succession overlap with the tree species of the later climax and subclimax forests, around 70 years post-abandonment. Richness declines as hardwoods replace the pines (100 to 125 years) to increase again around 150 years as new hardwood species appear. The hardwood stage lasts from 100 years, post abandonment, to 200 years or more.

Johnston and Odum[21] reported on breeding bird populations of the Georgia-piedmont sere. They found that both density and diversity increased with succession up to the pine stage where each declined sharply. Only one species, the pine warbler (Dendroica pinus), used the pine overstory, but other species came in as the hardwood understory developed. Approximately 12 species with 140 breeding pairs/40 ha (100 acres) were present before canopy closure and this dropped to 10 and 17 at 20 years. The maximum attained was 20 species and 240 breeding pairs/40 ha in the transition forest with 23 and 220 in the deciduous forest stage. Only the cardinal (Richmondena cardinalis) was present in all stages with most bird species being stage-specific.

On the North Carolina piedmont,[6] short-leaf pine (Pinus echinata) dominates the pine stage with up to 7400 stems/ha (3000 stems/acre). The first oaks (Quercus spp.) appear at about 20 years with the first hickories (Carya spp.) only a few years later. The sequence during the first 3 years was given by Keever.[22] Crabgrass (Digitaria sanguinalis) is able to invade plowed fields in the fall of the year of abandonment because of its drought resistance and ability to germinate under cool soil temperatures. Horseweed (Leptilon canadense) may germinate at about the same time but grows to maturity the following summer. Horseweed and ragweed (Ambrosia elatior) dominate one-year-old fields with germination of new horseweed seeds being inhibited by the decay products of the parent plants. An aster (Aster pilosus) appears the first year and becomes a dominant the second, along with ragweed and buttonweed

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*See Glossary for definitions of terms.

(*Diodia teres*). A few broomsedge (*Andropogon virginicus*) plants appear the plants appear the first year but require 2 years to set seed. They become dominants by the third year.

On the Virginia piedmont, Virginia pine (*Pinus virginiana*) dominates the pine stage producing a closed canopy within 10 to 20 years. They mature within 50 to 70 years.[19]

Further inland, the old-field stage in middle Tennessee is characterized by elm (*Ulmus americana*) and hackberry (*Celtis occidentalis*) with an understory of broomsedge (*Andropogon virginicus*), goldenrod (Solidago altissima), aster (*Aster pilosus*) and panic-grass (*Panicum* sp.).[39] Sassafras (*Sassafras albidum*) may be a component of old-fields and, because of allelopathy, may persist in pure clones into the mature forest.[16]

3.3.2.2 Northeastern States--

Long-term succession in New England has been described earlier.[17] Bard[2] described secondary succession on the New Jersey piedmont. The first-year dominants were ragweed (*Ambrosia artemesiifolia*) and evening primrose (*Oenothera parviflora*) with later dominants represented. They were replaced in the second year by a goldenrod (*Solidago nemoralis*). *S. nemoralis* remained important for 15 years when it was replaced by *S. juncea* which persisted for another 45 years or more. By the fifth year, an aster (*Aster ericoides*) became the dominant herb and remained important for another 20 or more years. Fifteen-year-old fields were dominated by broomsedge (*Andropogon scoparius* with *A. virginicus*) which remained important for another 45 years. Eastern red cedar (*Juniperus virginiana*) is among the first woody invaders (2- to 3-year-old fields) and is the major arborescent species for more than 60 years. Dominant shrubs are brambles (*Rubus flagellaris*) which reach their peak 25 years after abandonment and poison ivy (*Rhus radicans*) which is most abundant 60 years after abandonment. The trees of the climax oak-hickory forest enter before the red cedar is mature and are well established in the understory by the sixtieth year after abandonment. Recent evidence[20] indicates that allelopathy is important to the early replacement of species. *Aster pilosus*, a second-stage dominant, was shown to produce a chemical which inhibited germination of first-stage dominants.

There is a succession of animals which follows the plant succession. Kircher[25] showed that bird diversity increased with each seral stage and that there was a gradual shift during succession from species which used the area for feeding only to species which nested in the area. Pearson[37] reported that small mammals increased with early succession but declined as the forest became established.

At least occasionally, the orderly replacement of species becomes delayed when one or more species establishes a stable, persistent community prior to the expression of climax. Examples include[34] speckled alder (Alnus rugosa) for 20 years or more, witch-hazel (Hamamelis virginiana) for 40 years, nannyberry (Viburnum lentago) for 45 years, and meadowsweet (Spiraea latifolia), highbush blueberry (Vaccinium corymbosum), lowbush blueberry (V. angustifolium), arrowwood (Viburnum recognitum), sweetfern (Comptonia peregrina) and common juniper (Juniperus communis) for 47 years. Thus, the typical succession cannot be expected in every instance. Nor is it possible to predict the frequency of occurrence or duration of stable shrub stages.

3.3.2.3 Central States--

Early succession in southern Illinois was described by Bazzaz.[3] Following the harvest of corn in August, cover was provided by weeds already established, including Solanum carolinense, Ambrosia artemisiifolia and Digitaria sanguinalis. During the first growing season following abandonment, annuals (plants which complete their life cycle in a single season) were the dominant vegetation and included Alliumvineale, Digitaria sanguinalis, Geranium maculatum and Aster pilosus. Sawbrier (Smilax glauca) was the first woody plant to become established. Total ground cover was approximately 65 percent.

Perennials (plants which live for several years) were the dominant vegetation by the second year of abandonment. Erigeron annuus flowered in early summer, when it was the conspicuous dominant, and Aster pilosus was most conspicuous later in the summer. Ground cover attained approximately 115 percent.

By the third year, erosion had reduced ground cover to approximately 85 percent, but the species replacement pattern continued. Herbaceous vegetation had begun to develop strata with goldenrod (Solidago nemoralis) dominating the upper stratum and panic grass (Panicum dichotomum) and three-awn (Aristida dichotoma) codominant in the lower stratum. Old-field shrubs began invading, including black raspberries (Rubus occidentalis) and persimmon (Diospyros virginiana).

Four-year-old fields had produced a stable herbaceous community, dominated by broomsedge (Andropogon virginicus). The developing shrub layer contained persimmon, sassafras (Sassafras albidum), elm (Ulmus alata), eastern red cedar (Juniperus virginiana) and sumac (Rhus spp.). Cover (all strata summed) had increased to 119 percent, with 8 percent being contributed by shrubs. Vegetation of 10- and 15-year-old fields remained similar in composition with the shrubs growing to a cover value of approximately 16 percent. By the 25th year, the older sassafrass and persimmons had produced a tree layer with the composition of the shrub and herb layers as before.

By 40 years after abandonment, the tree layer had reached a basal area of about 15.6 and the shrub layer had increased to 21 percent. Broom sedge still dominated the herb layer. Elm and sumac remained the dominants in the shrub layer but a few seedlings of the climax oaks (Quercus imbricaria and Q. velutina) had appeared. A total of 22 species occurred in the tree layer with sassafras and persimmon remaining the dominants.

The rate of invasion of the climax oaks was considered to be dependent on the proximity to mature forest, since the seeds were dispersed by squirrels which prefer the forest edge. Diversity increased throughout the succession to a maximum in the forest stage[4] but may be low when allelopathic species are present. Environmental heterogeneity produces a variety of seres within a given area.

The animals which occupy seral stages change with the vegetation. Sly[42] reported that deer mice (Pereomyscus maniculatus) occurred in the early, grass stage of successions while the white-footed mouse (P. leucopus) occurred in the later, forest stages. The two species overlapped during the old-field or grass-shrub stages. Seral stage is not the only determinant of acceptability to wildlife, however. Beckwith[5] concluded that the size of a tract of otherwise suitable vegetation would influence whether or not game animals would be found there.

3.4 CLEAN-UP PROCEDURES, EFFECTS ON ECOSYSTEMS

This section describes the effects that the proposed cleanup methods can be predicted to have on deciduous forest ecosystems. The description is qualitative for each treatment's impact in the ecosystem. A quantitative assessment of all the cleanup methods is deferred to Section 3.6, after the impact is described and the likely time course of recovery is given (Section 3.5). The cleanup treatments range in severity from a light spray, of "tacky" chemicals over the vegetation and soils, to severe impacts caused by removing vegetation and topsoil, mixing the subsoil with caustic chemicals and compacting the mixture with cementing agents.

(0-1) Natural Rehabilitation

For manual cleanup of contamination, no significant impact on the prairie is anticipated to be evident after 2 or 3 years.

(1-1) Chemical Stabilization

Properties of the two general classes of chemical stabilizers are given in Appendix A, Stabilizers. Twenty-seven are rated "preferred" for reducing soil erosion under normal rainfall regimes in the deciduous forest. Six allow seed to germinate in place but they break down in a year. Four of the six chemical stabilizers are safe to handle without special equipment, in machine or hand sprayers. Significant leaf fall from shrubs and trees is caused by the four stabilizers but little damage to roots is expected.

The application of stabilizers that kill vegetation is acceptable when vegetation to which they are applied must be removed in some of the cleanup methods described in subsequent discussion (treatment 1-3). In general, the plant-damaging stabilizers leave a more weather-resistant and erosion-inhibiting coating over soil surfaces.

(1-2) Clear Cutting Vegetation

Clear cutting deciduous forest is used in forest management. Clear cutting or block cutting permits reproduction from nearby forest trees, but public acceptance has been a major obstacle to the practice.

Clearcut forests revegetate in two ways. First, many species have the ability to produce sprouts from the stumps and roots of the former trees.

Since the remaining root network is essentially that of a mature tree, sprouts typically show exceedingly rapid growth. A coppice forest, which clear-cutting produces, can produce canopy closure in a decade or two. Since growth is from the remains of the former forest, species composition is typically quite similar. In addition to sprouts, the opening of a forest by clear cutting allows for invasion of pioneer species and an abbreviated version of old-field succession. The resultant, short-lived heterogeneity is attractive to game species. Those pioneer species which grow rapidly enough and can survive canopy closure add to the diversity of the resulting forest. Consequently, coppice forests may differ in that respect from the original forest.

(1-3) Stumping and Grubbing

Removal of stumps and roots blocks the formation of a coppice forest and results in longer recovery times. A natural succession would be similar to post-agricultural recovery and include the typical annual-perennial-shrub-tree sequence of dominants. The rate at which these stages replace each other will depend on what seeds were present in the soil prior to cleanup, the size of the affected area and erosion. This treatment will differ from post-agricultural land in that the seeds of species present when the treatment began can be expected to remain behind. The time-lag before the climax species appear as seedlings would thus be reduced to about a year and the total ecosystem development reduced accordingly. Thus, the up to 250 years required for reaching climax following agriculture might be reduced to 100 years or less. Assuming that the forest removed was not climax but an earlier successional stage, the time required for recovery to that point would likewise be shortened, with the exception of early shrub stages. Since woody shrubs appear very early in succession, typically the first or second year, and require several years to attain dominance, no shortening of that interval would be expected.

The size of the affected area influences the invasion rate from outside the area. Small (i.e., 0.1 km^2) areas have large perimeter to area ratios compared to large areas (i.e., 10.0 km^2). Since squirrels prefer forest edge,[3] acorns could be expected to be buried over the smaller areas more quickly than the larger one with a proportional recovery of oaks.

Uncontrolled erosion can act as a recurring perturbation which continually sets back recovery in the cleaned-up area to an earlier stage, and can expand the perturbation beyond the spill zone. Thus, presence of erosion will result in longer recovery times and larger perturbations.

(1-4) Scraping and Grading

In a forest, scraping and grading requires that stumps first be removed. In addition to the effects of stumping and grubbing (1-3), scraping and grading (1-4) would remove the surface organic matter that remained. That would result in higher soil temperatures, decreased infiltration of water, increased runoff and erosion and nutrient depletion. As a result, recovery times could reasonably be expected to be longer than with stumping and grubbing (1-3) alone, but not as long as required for post-agricultural recovery since some seeds would remain in the soil. The pattern of recovery would be expected to remain the same with the size of the area affecting the rate as well. It has been found in strip-mine reclamations that scraping and grading (1-4) delays recovery relative to a rough surface, primarily because of a reduction in infiltration and an increased risk of erosion.

(1-5) Shallow Plowing

Shallow plowing (<10 cm) following stumping and grubbing would probably have no observable effect on ecosystem recovery beyond that of vegetation removal. The surface organic matter would be incorporated into the soil and seeds redistributed, but the long-term effects would not likely be discerible. The effect would be less than soil removal because the seeds and organic matter would remain and because the resulting pattern of ridges and furrows would trap water and decrease erosion.

(1-6) Deep Plowing

As recently as the early 20th century, farmers in the deciduous forest zone cleared and planted "new ground." Trees were killed by girdling and then felled and usually burned. The farmers then plowed their fields, although cutting through the buried roots was punishing to both mule and man. They plowed partly out of tradition and partly to keep down weeds, that is, to prevent natural succession. Deep plowing as a cleanup procedure will do the same, except being done only once the effect will be shorter-lived. Thus, deep plowing on deep soils may delay early succession a year or two. Deep plowing on shallow, hill soils can be expected to have a longer-lasting effect, if it can be accomplished at all. In either case, the effect will be less than grading or soil removal, since the quality of the seed bed remaining should be superior to that left by soil removal and the ridges and valleys will retain precipitation. The succession should be no slower than post-agricultural successions on similar soils.

(1-7) Soil Cover Less than 25 cm

The addition of uncontaminated soil to a forest floor has several potential effects, not the least of which is the disruption of vegetation by the application of the soil. One acre-furrow-slice (the soil of one acre to a depth of 6 inches) weighs 2,000,000 pounds or more.[10] Therefore, covering 0.01 km^2 with 25 cm of soil would require at least 3.7×10^6 kg (8.2×10^6 lbs or 4×10^3 tons) of soil and up to 3.7×10^9 kg for 10.0 km^2. Such large masses of soil require heavy earth-moving equipment which cannot be operated in a forest without first removing or knocking down the trees. It must be assumed, therefore, that any soil additions will be done after the forest is removed.

Twenty-five centimeters of soil or less would not cover the fallen boles and stumps of mature deciduous trees, leaving the possibility that at least some of the trees might resprout from unkilled tissues. The severity of the impact then would lie somewhere between that of a clearcut forest, assuming a greater kill rate, and surface alterations. Herbaceous material would be buried below an effective recovery depth and the seeds present on the forest floor would be too deep to germinate. Consequently, recovery would consist of a combination of resprouting of the former trees and invasion of pioneer species, including the seeds carried in the uncontaminated soil. As such, recovery rate would depend upon the area disturbed, which affects the invasion rate of trees, the kinds and amounts of seeds contained in the imported soil, the seed-bed quality represented by the imported soil and sprouting rate of the fallen trees. All of these interact to produce a range of variables which greatly diminishes predictability.

(1-8) Soil Cover 25 to 100 cm

Covering with additional soil primarily magnifies the problems identified in the previous section. As depth of added soil increases, the probability of resprouting of fallen trees decreases. A full 100 cm of soil would cover most of the fallen boles and many of the uprooted stumps. Resprouting cannot be completely ruled out as a recovery factor, however.

Since noncontaminated soil must be excavated elsewhere, it is safe to assume that seed-bed quality will decline with the area and depth to be covered. That is, constraints on disturbing noncontaminated areas will require the decontamination crews to dig deeper at the borrow site as volume demand goes up rather than to increase the area disburbed. In most regions, that translates as a lower quality seedbed. Thus, recovery time may be expected to be extended as area treated and burial depth are increased. Quality of the seedbed would be the primary factor affecting early recovery with the size of the area disturbed affecting later rates of invasion by trees.

The level of impact would be expected to be greater than that of vegetation removal, surface alteration, plowing, and possibly soil removal. The one ameliorating factor would be resprouting of fallen trees, if it were to occur.

The environmental costs of disturbance to the borrow sites must be factored into any cost-benefit analysis of burial procedures. For even the smallest area considered (0.01 km^2), 2500 m^3 soil would be required for burial to 25 cm and 10,000 m^3 soil would be required for burial to 100 cm. Because of the desire to minimize the area affected, the impact on the borrow site would be greater than that of any of the cleanup procedures considered, with the exception of hard-surface stabilization.

(2-1) Remove Plow Layer

The effects of removing the plow layer, approximately 15 cm (6 inches) of soil, depend upon topography, soil type, and what other cleanup procedures are done in conjunction. Deciduous trees, growing in forests, have roots in contact with the surface organic layer. This is where the active exchange of nutrients occurs. Assuming it is possible to remove the top 15 cm (6 inches) of soil without first removing the trees, it is probable that no tree would survive the cleanup. While the presence of standing, dead trees would not be expected to interfere with recovery, they would also not expedite it, leaving no justification for not removing them.

Assuming removal of the plow layer to follow stumping and grubbing, the pattern or recovery would be that of, at best, a post-agricultural succession or, at worst, a strip-mine spoil. All plants would have to invade from outside the area making the size of the affected area important. If the cleanup were to occur on nearly level topography having well-developed soils, the remaining seed bed could be of high quality. In steep terrain, however, forest soils typically have a very thin (less than 15 cm) layer of topsoil which would be removed entirely. The resulting seed bed would resemble mine spoil and ecosystem recovery could be expected to be accordingly slow. Subsequent chemical and most types of mechanical subsoil stabilization have little added impact but would minimize erosion in the short term recovery.

(2-2) Remove Shallow Root Zone

In deciduous forest, shallow root zone can be interpreted to be a plow layer or less. At any rate, soil removal is also seed removal and the early colonizations must be from outside of the affected area. Increasing the depth of soil removal lowers the probability of leaving a suitable seed bed and increases the time necessary for recovery. Whereas canopy closures can occur within 30 years in post-agricultural successions,[32,33] such rapid recovery is unusual following surface mining[13] which is analogous to soil removal on shallow soils. Use of chemical and mechanical stabilizers to prevent erosion would mimic post-agricultural recovery.

(2-3) Remove Scraping and Grading, Mechanically Stabilize

As the sizes of stabilized areas increase more internal structures are needed for overland water control. These include dikes, berms, drainage ditches, shaped waterways and overfall structures on steeper-grade channels which are all beyond the scope of this presentation.

The specific consequences of scraping and grading (1-4) were presented earlier and apply to the pre-stabilized deciduous forest. Denuded areas depend on early reseeding by native plants. A smoothed and compacted surface having reduced water permeability is the medium represented after erosion control by stabilization.

Mechanical stabilization may involve compaction, meshes, mulches, deflocculants, and clays. The effects of mechanical soil compactors remain evident for many years. Complete recovery will seldom occur by 100 years. Simple ground cover by plant invaders will take up to five years and succession may be delayed 25 or 100 years compared to simple clear-cutting. Heavily compacted areas are subject to repeated regressive cycles following erosive denuding of large open areas. Infiltration can readily be reduced to an inch per hour or less and offsite runoff is a serious problem at even one hectare of clearing and surfacing.

Non-compacting stabilization by meshes and mulches is indicated for the cleared, deciduous forest and is the method rated in Table 3-2 (see Section 3.6). This assumes that mesh is held down by pegs (non-metallic if mowed) on steep slopes and anchored to prevent wind detaching or under-running sections. Mulches are anchored by tractor disc or cleats in areas free of significant water erosion.

Deflocculants and clays have characteristics that produce impacts intermediate among soil compactors and the various mulches. They are subject to frost heaving damage and are relatively short-lived since seeds can collect and germinate in the breaks. Deflocculants depress the early growth of plants by salt effects in germination and rooting compared to clays.

Significant damage by small rodents is probable in a few months for any of the chemical and mechanical stabilizers used after soil removal.

(2-4) Remove Plow Layer, Mechanically Stabilize

The ecological impacts were described in scraping and grading (1-4) and the effects of stabilizing the exposed soil mechanically were defined in treatment 2-3. In general, natural recovery will be delayed compared to removing 5 cm or less of soil, by removal of more seed sources and mechanical stabilization will seriously retard revegetation compared to clear cutting.

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

This treatment has effects almost identical to plow layer removal (2-1). Soil fertility is reduced by deeper cuts and the potential for natural revegetation shifts to favor invaders instead of local pioneer species. The subsoils will tend to be more erosive than surface layers due to reduced organic matter and so require heavier applications of stabilizers. Higher clay content will increase density under compaction and exacerbate water erosion. Non-compacting stabilizers are much superior in this case.

(2-6) Remove Scraping and Grading, Chemically Stabilize

The physical effects and the ecosystem impact of removal of scraping and grading (2-6) were described under treatments 1-4 and 2-3. The effects of chemical stabilizers are less durable than those of mechanically stabilized soils and require prompt revegetation, usually by herbs and grasses in the clearings made. Either class of stabilizer reduces surface erosion, increases runoff, and has specific effects on water infiltration according to the specific stabilizer and its limits of use (Appendix A, Stabilizers).

Chemical stabilizers for soil stabilization control soil erosion while seedlings become established then the "preferred" stabilizers break down. Overland runoff is reduced by these compounds compared to soil compaction treatments. Stabilization with chemicals will reduce erosion of the exposed soil horizons and should allow early revegetation of native pioneer species.

(2-7) Remove Plow Layer, Chemically Stabilize

The effects of removal of the plow layer (2-1) are combined with those of treatment 2-6. The deeper soil cut reduces the seeded zone to those hidden by small animals and exposes the infertile subsoil as the plant growth medium. It presents a hostile environment to transplants and invader species and a lengthening of the time for recovery. Compared to the time required for recovery to climax the delay is probably negligible in the long term. Chemical stabilizers would be the method of choice for revegetating the cleanup zone.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

The effects of removing the surface soil to a depth of 40 cm increase the problems of revegetating in the infertile soil over treatment 2-7 and eliminate revegetation by local pioneer species. The limited potential for recovery favors exotic invaders. Low organic matter increases runoff to a serious erosion threat and heavy applications of chemical stabilizers are called for, including those that are not acceptable after other cleanup (Appendix A, Stabilizers). Chemical stabilizers of three to five year durability are highly toxic and rehabilitation is required before revegetation will succeed. This is one of the four deciduous forest cleanup treatments that require intervention by reclaimers before it can start recovery towards the original productivity. If not reclaimed the area will be lost to erosion processes.

(3-1) Barriers to Exclude People

Natural ecosystems can be benefited by excluding humans from the area without any impact on the plants, soils, and wildlife.

(3-2) Exclude Large Animals

Barriers which restrict large animals only will have a greater effect on the animal populations themselves and not on ecosystem structure and function. Large animals were once nearly exterminated from deciduous forests but several species are now recovering. White-tailed deer (Odocoileus virginianus) feed in old fields and have increased their numbers as agricultural land has been abandoned. The fencing-off of small tracts (0.01 km^2) would not represent a significant proportion of available habitat, but the maximum tract (10.0 km^2) could seriously limit the habitat of a local population. Even so, the effect would be insignificant on a regional or state basis.

(3-3) Exclude Large and Small Animals

The erection of barriers to prohibit animal crossings affects only ground-dwelling vertebrates without impacting soil and plants. Birds, insects and squirrels are not likely to be restricted by any barrier which meets engineering and cost acceptability. Nor are small mammals and reptiles likely to be successfully removed with the enclosure of the area. Thus, species composition of an area would be virtually unaffected by the erection of barriers. Restricting movement of animals into or out of the area would restrict gene flow but only the smallest area of concern would likely be impacted and then only if the barrier remained intact for several decades. The effect on large mammals is treated in the next paragraphs.

Black bear (Ursus americanus) are also recovering in the deciduous forest region. Omnivorous animals which thrive on the absence of human contact are showing the greatest recovery in back country forests of the eastern mountains. One of the healthier populations exists in the Great Smokey Mountains National Park, an area of 1865 km^2. The maximum area considered, 10.0 km^2, is only 0.5 percent of that area, which could not be construed to be significant. Fringe populations might be impacted more heavily, however.

The eastern cougar (Felis concolor cougar) is also recovering from former population declines and is being sighted with increasing frequency. Home ranges are not well-known, but it appears certain that a viable population requires areas many times larger than the largest cleanup area considered. Thus, habitat reduction is not expected to be a factor. Potentially more important is the effect that closure might have on migratory routes. Large predators must travel great distances hunting prey or risk depletion of their food source. In the eastern United States, that usually means passing through frequent narrow corridors between heavily populated areas. Closure of those corridors could seriously restrict the home range of cougars and affect their recovery. Impact on the species could be serious.

(4-1) Asphalt Hard-Surface Stabilization

Paving a spill area with asphalt represents the most severe impact considered so far. Any plant invasion or animal utilization of the area would be delayed until the asphalt begins to decompose, possibly a decade after treatment. Establishment of a community would require fairly complete decomposition of the asphalt which would require further decades. The impact of an asphalt surface over 0.01 km^2 might be acceptable if the area originally was of low value ecologically, but not if the area has the potential for production of a rich community. It is not possible to consider acceptable a paving cover of 0.1 km^2 or more. Even the most disruptive of the high priority techniques, soil removal or burial, would have significantly lower impact.

(4-2) Concrete Hard-Surface Stabilization

The effects of paving with concrete are qualitatively the same as with asphalt and the primary evaluation is the same. Since concrete decomposes more slowly than asphalt, the effects would be longer lived and thus less acceptable than those of asphalt.

(5-0) Application of Sewage Sludge

Application of sewage sludge can replace organic matter and plant nutrients lost in vegetation removal and help balance soil pH for better nutrient availability.[15,27,41] The result is more rapid surface stabilization and encouragement of plant growth. The amendment is not without problems, however. Municipal sewage commonly contains heavy metals which can be toxic, particularly to higher organisms. A potential exists for impacts on wildlife and food-chains leading to man. Secondly, a potential exists for saturation of the soil cation exchange complex with excess ions leaching into streams. This problem has been demonstrated for liquid effluent[38] but could become a problem with sludge, as well. On graded land sludge could reduce runoff and erosion by increasing infiltration, which would speed recovery.

(6-1) High Pressure Washing (<3 mm)

Outside the scope of work of this study.

(6-2) Flooding to 30 cm

Outside the scope of work of this study.

(7-0) Soil Amendments Added

Outside the scope of work of this study.

3.5 RECOVERY FOLLOWING CLEANUP

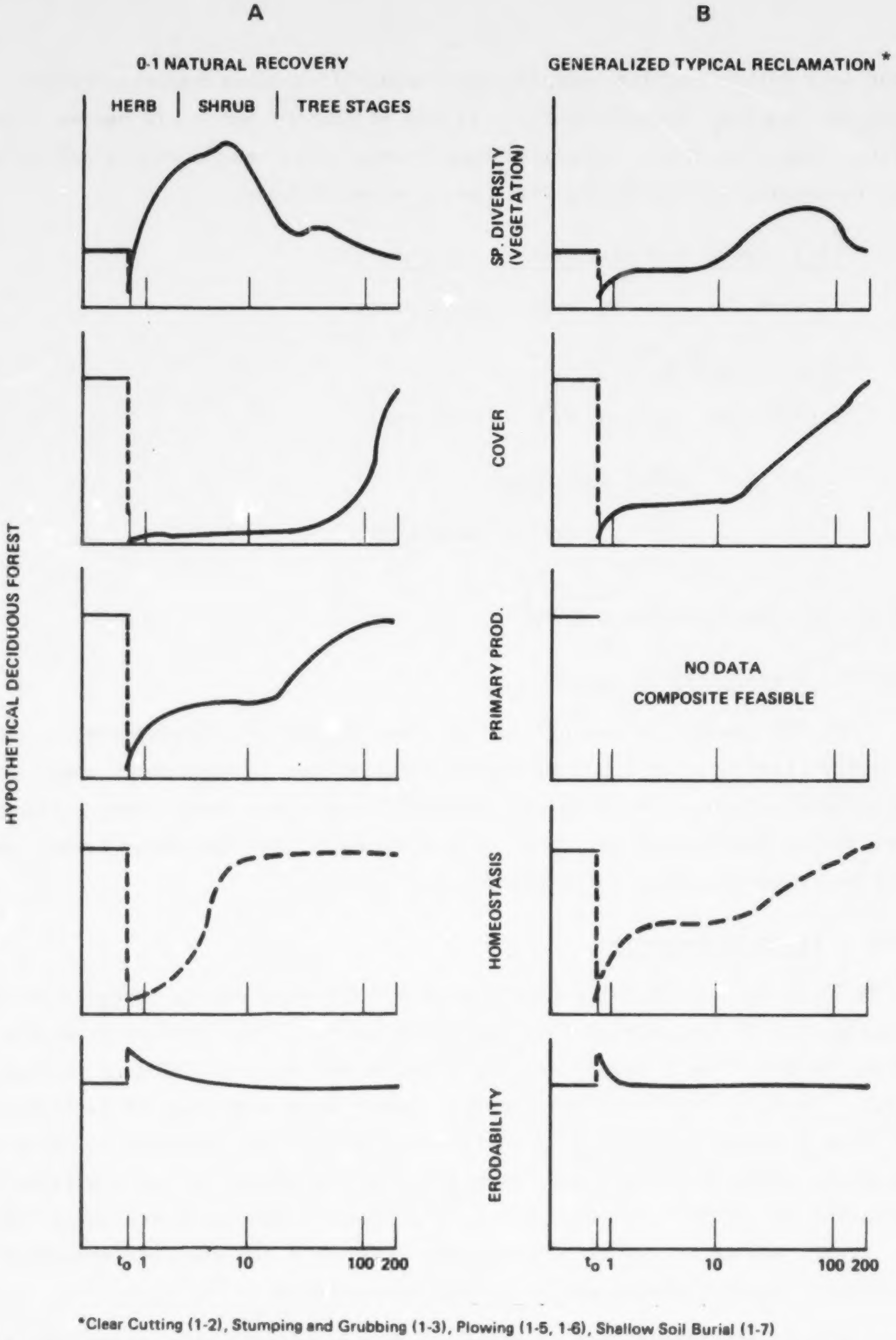
3.5.1 Irreversible Changes

In the context of geological time, no changes are irreversible. Hard surface stabilization would be expected to produce changes which would persist long enough to be considered as irreversible in a practical sense. All other treatments fall within the range of experience in the deciduous forest region for which revegetation has occurred.

3.5.2 Rates of Recovery

The deciduous forest biome is probably the most easily revegetated of the various native terrestrial land types considered. This results primarily from the fact that rainfall is both abundant and well-distributed through the year. Thus, given a suitable seedbed, plants face a minimum of factors limiting establishment. If theseedbed is not suitable, the abundant rainfall and moderate temperatures provide for more rapid weathering of the substrate and creation of seedbed. Smith, et al.,[43] actually found increased levels of N, P, K, Mg, and Ca in leaves of sassafras grown on a 100-year-old iron-mine spoil in West Virginia, when compared to contiguous soils.

Figure 3-1 illustrates a series of characteristics during recovery from a major disruption, without reclamation (A) and with reclamation (B). The



*Clear Cutting (1-2), Stumping and Grubbing (1-3), Plowing (1-5, 1-6), Shallow Soil Burial (1-7)

Figure 3-1. Natural recovery (0-1) and generalized typical reclamation of deciduous forest following cleanup (after Whittaker[46]).

processes are generalized and thus do not relate to a specific location. The major disruptions include severe vegetation removal, surface alteration, soil removal, plowing and soil fill. The time units are approximate with variability resulting from local differences within treatments and between treatment differences. The ordinate (Y-axis) is without units either because it is dimensionless (e.g., homeostasis) or site specific (e.g., primary productivity, species diversity). See Appendix B for further use.

Species diversity increases from the bare-ground stage to some maximum occurring during a transition from one major stage in succession to another. In the example shown, the maximum occurs during transition from the herb stage to the shrub stage, approximately 15 years after the sere begins. In other successions, the maximum diversity might occur at the transition from the shrub to tree stage (approximately 50 years) or as the climax forest replaces a subclimax forest (perhaps 150 years). Reclamations seed a mixture of plants, particularly legumes such as sericea lespedeza and black locust. Seeding creates a diversity which may be greater than early seral stages but which, through competition, do not yield to the waves of early invaders typical of early successions. Thus, species diversity may remain low for a number of years. The highly diverse old-field stage may be essentially bypassed with the result that the maximum diversity obtained may be less than the maximum attained by a natural sere. The end point is the same, however, and a climax forest resulting from a reclamation-based sere is presumed to be similar to the climax resulting from a natural sere.

Cover increases gradually during natural successions, becoming more rapid as trees replace the earlier stages. Mature forests with their distinct layers produce the greatest cover of the sere. Reclamations are similar except that greater initial cover is possible by seeding, but cover may not increase until trees are able to overcome the early cover species.

Primary productivity generally increases with community age, reaching its maximum in the mature forest. The rate of change may not be constant, however, but depend upon the rate of species replacement. Thus, if a persistent seral stage is established, the primary production rate may be essentially constant for several years.

In general, homeostasis increases with community development with the climax forest representing the most stable state (generalized typical reclamation curve). In some instances, shrub stages attain a high state of homeostasis (natural recovery curve) and persist for several decades.

Erodability increases sharply with a perturbation but declines as vegetative cover protects the soil. During natural successions, erodability remains higher in early stages than the later stages, although the most rapid decline occurs during the first few years. The main point of reclamation is to quickly reduce erosion. By seeding directly to a grass-shrub stage, the first several years of succession are compressed into 2 or 3. Consequently, erodability drops sharply as cover is established and declines in accordance with increased cover thereafter.

3.5.3 Succession Stages Following Cleanup

3.5.3.1 First Year--

During the first year following treatment, the clearcut forests would begin to produce sprouts from the remaining stumps (Figure 3-2A). The spring flowering herbs of the former forest should reappear as usual. The opening of the forest would also permit the invasion of pioneer plant species from outside with ragweeds (Ambrosia spp.) and other annuals being among the first invaders. Perennial grasses, such as broomsedge (Andropogon virginicus), and even woody plants may also invade but typically do not become conspicuous. With the exception of the sprouts, areas which have been stumped and grubbed (Figure 3-2B), scraped, graded, plowed, or had soil added or removed should experience a similar first year. Cover would remain low on all treatments but especially on those leaving the poorest seedbed, such as removal of the shallow root zone or burial with up to 100 cm soil. No plant invasion could be expected on soils with hard surface stabilization.

Animal use of first year successions would be limited. Insect herbivores could be expected and, consequently, avian insectivores. The low productivity could not support a large consumer biomass, however. Cover on first year fields is too low to support resident bird populations and the small mammals found there are transients, as well. Large mammals would not find the area attractive.

Areas around which barriers were erected should not be visibly different after one year. Soils and plant cover have no visible impact following erection of barriers (Figure 3-3), or after flooding with a few cm of water.

On denuded areas receiving sewage sludge, first year germination success and growth would be expected to exceed that of bare ground. The greater cover would support a larger consumer biomass but no vertebrates would be expected to become residents during the first year.

3.5.3.2 Fifth Year--

Five years following cleanup, most procedures should be represented by a stable herbaceous community. In central Tennessee,[39] similar aged fields were dominated by broomsedge (Andropogon virginicus) and aster (Aster pilosus). In southern Illinois,[3] broomsedge was also dominant. Woody vegetation invades by the fifth year and includes persimmon (Diospyros virginiana), sassafras (Sassafras albidum), elm (Ulmus alata), eastern red cedar (Juniperus virginiana), and sumac (Rhus spp.). Ground cover is high, about 119 percent in the Illinois example, but the woody vegetation contributes only a small fraction of the cover.

Where disturbance was less than that represented by post-agricultural successions, such as clear cutting, recovery would be more advanced. Root and stump sprouting could produce a dense copse woodland in five years which might prove to be attractive to deer and other forest-edge wildlife. Herbaceous groundcover should remain dense because canopy closure would not be expected to occur within five years. If the treatment had been to simply erect barriers, no visible differences would be expected between treated and untreated areas.

Soil stabilization by compaction, binding agents, or flocculating agents would probably no longer be distinguishable from non-stabilized cleanups which left bare ground. Hard surface stabilizations would not be expected to have broken down or decomposed in five years and, consequently, there would be no recovery (Figure 3-3).

3.5.3.3 Tenth Year--

For the cleanups which left bare ground, the tenth year would be quite similar to the fifth year, differing primarily in the growth of the woody vegetation. More individuals of the same shrub species might also be expected. The characteristic old-field/shrub stage is quite attractive to wildlife, however. The clear-cut forest might achieve canopy closure by the tenth year,

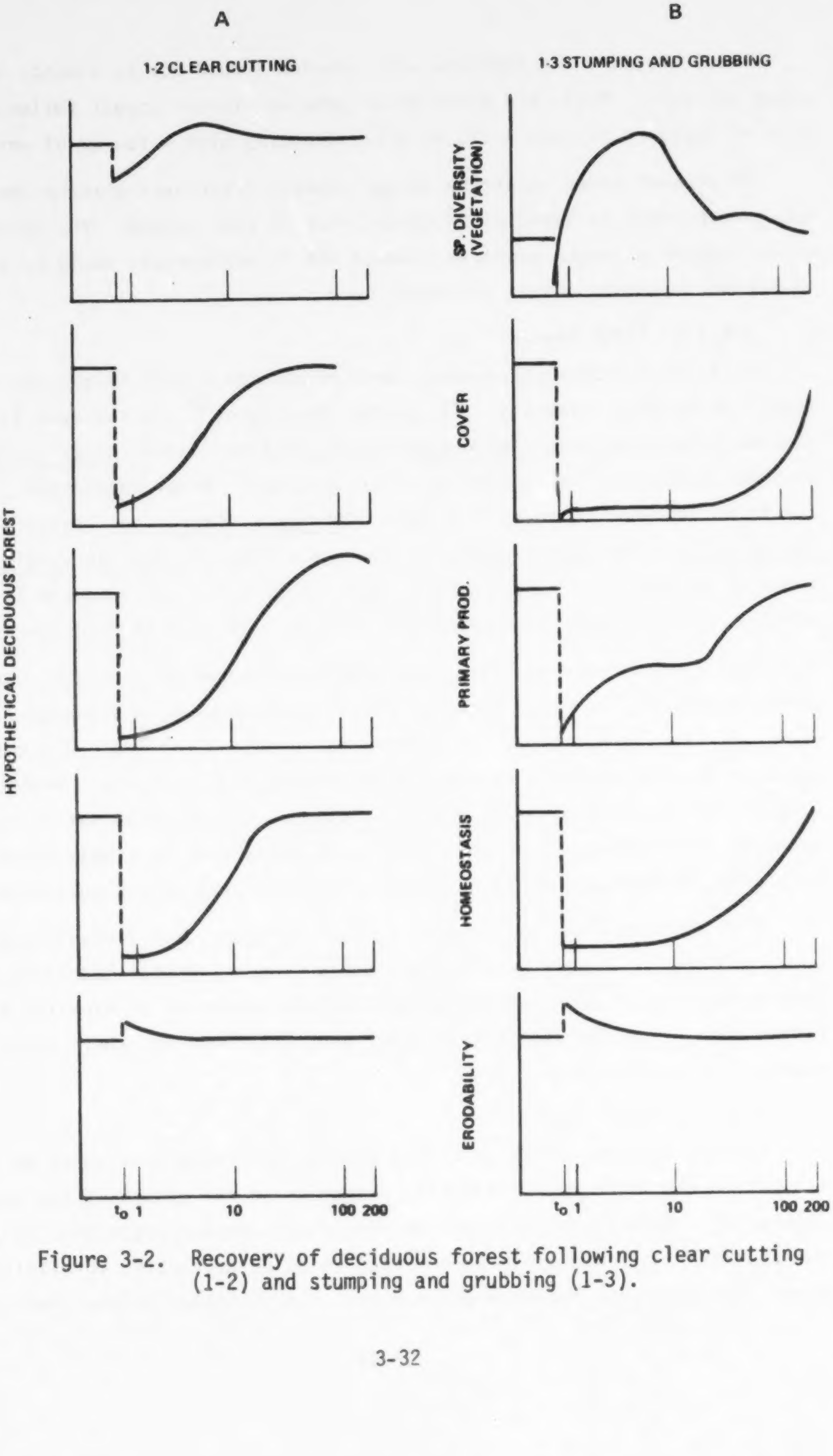


Figure 3-2. Recovery of deciduous forest following clear cutting (1-2) and stumping and grubbing (1-3).

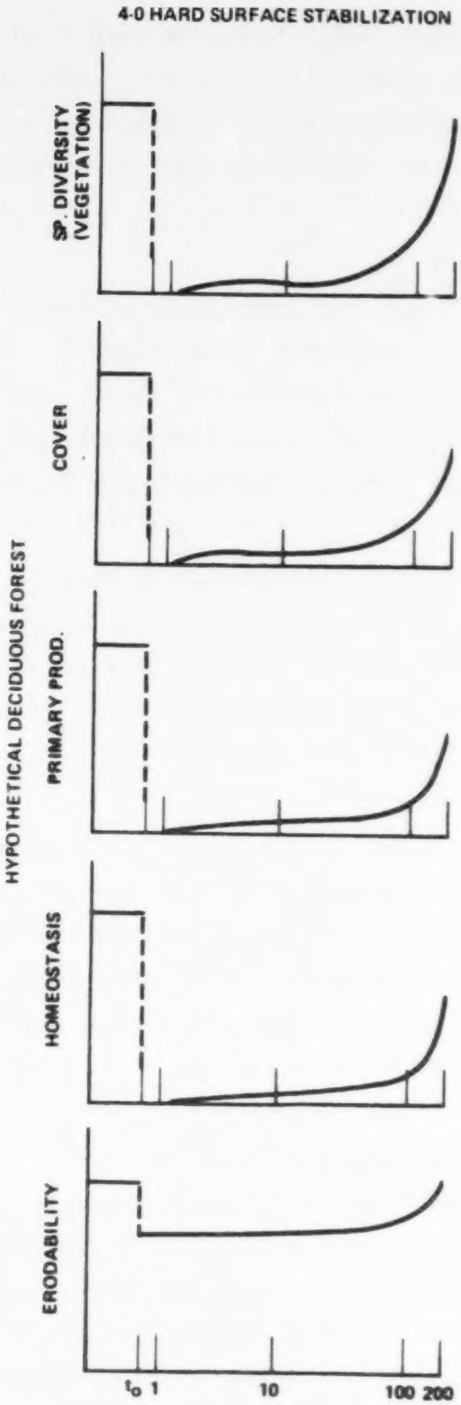


Figure 3-3. Recovery of deciduous forest following hard surface stabilization.

if sprouting had been vigorous, and, if so, the herb stratum would be declining. Hard surface stabilizations, particularly asphalt, could be starting to break up with pioneer species starting to invade cracks. Reclaimed land should have a mixture of trees, shrubs, and herbaceous vegetation which is attractive to wildlife.

3.5.3.4 Fiftieth Year--

In southern Illinois,[3] the local sere lacks a pine-forest stage. Consequently, 50 years of recovery would not likely produce a closed canopy. After 30 years, 22 species of trees were present but so was a perennial grass (Andropogon virginicus) layer, which indicates a high light level at the herb stratum. Seedlings of the climax oaks (Quercus imbricaria and Q. velutina) had begun to appear, indicating that a mature forest was less than 100 years away.

In the southeastern states, a subclimax pine forest typically replaces the shrub stage and can produce canopy closure within 30 years from the beginning of succession.[33] When canopy closure by conifers occurs, light to the forest floor is greatly diminished and the herb layer is largely eliminated. Consumers do not utilize pine forests to any great extent and, consequently, species diversity tends to be low.

Stumping and grubbing, surface alterations, soil removals, plowing, stabilizations, and soil fills should all be as described above. Clear-cut forests would likely have produced a closed-canopy, deciduous forest and be more advanced than the bare-ground treatments. Hard surface stabilizations would not be sufficiently decomposed to permit normal community development to progress although individual plants might be doing well. Reclaimed land could be expected to be in closed-canopy forest[1] but not in climax.[40]

3.5.3.5 100 Years After Cleanup--

Extrapolating from conditions at 50 years, forests lacking a pine stage should be approaching climax, although full growth and development would not be expected. In forests with a pine stage, 100 years marks the transition from pine to deciduous forest. In many seres, this is the point of maximum diversity and productivity, both declining into the climax. This point may contain the greatest density of breeding birds, if not the greatest diversity.[21] This peak in diversity, density, and biomass extends even to the populations of decomposers in the forest floor.[28]

One-hundred-year-old reclamations are not known but it seems reasonable to assume that the accelerated development during the first decade would no longer be evident and reclamations would be similar to natural revegetations. Neither are 100-year-old, abandoned pavements known. It is assumed that decay of either asphalt or concrete would be fairly complete after a century and revegetation would be proceeding. Vegetational composition and developmental stage is not predictable, however, because of the spatial and temporal heterogeneity which would result from the breakup pattern of the pavements. Where diverse microsites occur on mine spoils, the revegetational patterns do not conform to theoretical seres.[9]

3.5.3.6 Climax--

In deciduous forest, climax is more often a theoretical concept than an observable fact. Using the term loosely to mean forest dominated by a species complex similar to the climatic potential, whether or not mature, climax forest might be expected to occur 150 to 200 years following the disturbance. Assuming that the forest disturbed was climax, the new climax may or may not be the same. Woodwell[47] has suggested that man-made (anthropogenic) influences are changing the basic physical and chemical properties of the earth and may interfere with ecosystem development as we have understood it. If so, it is understood that these influences, such as acid precipitation, will retard rather than accelerate ecosystem recovery.

Deciduous forest is an extremely diverse biome with numerous local seres leading to a few climax types. In generality, natural successions from bare ground go through a series of defined stages: annual weed, perennial herbs, shrubs, trees. Often, one or more subclimax forest stages precede climax forest. Occasionally, metastable subclimax communities apparently resist invasion by trees,[34] possibly through allelopathy.[16] In other cases, periodic perturbations, such as fire, lead to subclimax stages.[36] All of these extend the full recovery time of ecosystems.

3.6 QUANTITATIVE ASSESSMENT OF CLEANUP IMPACTS

Of the cleanup procedures specified, stumping and grubbing (1-3), scraping and grading (1-4), soil removal (2-1 to 2-8), plowing (1-5, 1-6), and cover with uncontaminated soil (1-7, 1-8) are similar in that the rate and pattern of recovery will be similar. Differences which may be apparent during the first few years should no longer be apparent after a decade or so. Less severe disturbances lead to more rapid recovery, more severe ones recover more slowly.

Because of favorable moisture and temperature conditions, deciduous forests are reclaimed relatively easily. The growth form of mature communities, and their homeostatic mechanisms, prevent revegetation of climax species, directly. Trees of the climax forest typically do not do well on freshly reclaimed surfaces and the forest floor, which retains nutrients and retards erosion, requires years to develop. Consequently, reclamations can only shorten recovery time by about a decade, which represents only about 5 percent of the time required to replace a "climax" forest. However, reclamation can provide early vegetative cover over the entire area immediately which ameliorates erosive degradation in the cleanup area and gullying outside the spill zone.

Early stages of natural successions are low in diversity and productivity. Wildlife is not found on them. Reclamations attempt to seed directly to the grass-shrub stage which can establish valuable wildlife habitat within 5 years. Consequently, the benefits gained from reclamations go beyond simply reducing erosion or slightly shortening the sere.

3.6.1 Impact Assessment

Cleanup procedures in deciduous forest are indexed (See Appendix B) in Table 3-2 as impacts on ecosystems, with 0 equal to no impact and NA equal to complete loss of the ecosystem. The index estimates include consideration of the physical, biological and sociological impacts of the treatments on the nearby vicinity of the cleanup area. There are several caveats which must be observed. First, the numerical rankings are highly subjective. Secondly, as explained below, most impact rankings for a given procedure in a given ecosystem increase as the area affected increases. It is also likely that the confidence decreases as the area increases. Given enough time, tens of years to centuries depending on the treatment, recovery to a condition paralleling that of surrounding untreated areas would occur due to natural recovery. Thus the index values in Table 3-2 will tend toward 0 with time. Since the relative impact assessment is time dependent, the time selected for comparison was the first growing season after cleanup treatment.

Table 3-2. Predicted recovery index in deciduous forest for cleanup treatments (see Appendix B).

Treatment	Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	0	0	0	0	0 = no significant impact. Manual cleanup done
1-1 Chemical Stabilization	0	0	0	0	Surface applications by spray, broadcast
1-2 Remove Vegetation by Clear Cutting	2	2	2	2	Climax ~100 years by resprouting
1-3 Remove Stumps and Grub Roots	4	4	4	4	Seed sources intact, climax ~100 years (N)+
1-4 Surface Scraping and Grading (<5 cm)	4	4	4	4	Plants removed first
1-5 Shallow Plowing (<10 cm)	4	4	4	4	Plants removed first
1-6 Deep Plowing (10 to 40 cm)	4	4	4	4	Plants removed first
1-7 Soil Cover (<25 cm)	5	5	5	5	Plants removed, climax can be >100 years
1-8 Soil Burial (25 to 100 cm)	#	#	#	#	Can require rehabilitation, then ~100 years
2-1 Remove Plow Layer Soil (10 cm)	5	5	5	5	Plants removed first, climax >100 years (N+1)+
2-2 Remove Shallow Root Zone Soil (<40 cm)	#	#	#	#	Can require rehabilitation, then ~100 years
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	4	4	4	4	Vegetation removed first, climax near 100 years
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	5	5	5	#	Plants removed first, climax >100 yrs; rehab >10 km^2
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	#	#	#	#	Rehabilitation required
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	3	3	3	3	Plants removed first; early regrowth
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	4	4	4	4	Normal climax ~100 years
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	#	#	#	#	Rehabilitation probable, then ~100 years
3-1 Barriers to Exclude People	0	0	0	0	No climax retrogression
3-2 Barriers to Exclude Large Animals	0	0	0	0	No climax retrogression
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	No climax retrogression
4-1 Asphalt Hard-Surface Stabilization	NA	NA	*	*	Excessive recovery delay (N+2)
4-2 Concrete Hard-Surface Stabilization	NA	NA	*	*	Excessive recovery delay (N+2)
5-0 Sewage Sludge Application	0	0	0	0	Vegetation remains in place.
6-1 Washing (<3 mm)	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	
7-0 Soil Amendments Added	*	*	*	*	

*Outside scope of work.

+Normal climax in ~100 years; methods of indexing in Appendix B, symbols defined (5, #, NA) and Guide Numbers (N, N+1, N+2) in Table B-5.

The rationale for a particular index value is discussed in Section 3.4 and summarized here. Intermediate impact rankings are explained in Appendix B. Impact of clear cutting (1-2) on deciduous forest is related to the time required for succession, hence the possibility of root sprouting lowers the impact relative to stumping and grubbing (1-4). Impacts obviously increase with area. Scraping, burial, plowing and soil removal were all considered to be impacts in addition to forest removal, for trees and shrubs would generally have to be removed before the other procedures could be applied. Scraping and grading (1-4) are not considered to be any more disruptive than stumping and grubbing (1-3) since both preparation and the results are similar. Shallow plowing (1-5), over a large area, would be a slightly greater impact since herbaceous plants and seeds would be buried. Deep plowing (1-6), if possible, on many forest soils would bring lower quality subsoil to the surface and result in a degraded seed bed. Removal of the top 10 cm (2-4) would remove local seeds and require plant invasion from outside of the area. Hence, resulting in a greater impact and an increasing impact with areal increase. Thinner topsoils would also be removed. Removal of up to 40 cm would remove virtually all forest topsoils and leave poor seed beds. Similar arguments apply to burials. Barriers to exclude people (3-1) would have no impact while barriers to exclude animals (3-2, 2-3) might have slight impact over large areas. The impacts to animal populations themselves might be greater. Hard-surface stabilization (4-1, 4-2) is effectively a complete, permanent loss.

3.6.2 Recovery assessment

Deciduous trees require decades to reach canopy height. Consequently, any area where trees are removed will not be soon restored to its former state. Furthermore, climax species have habitat requirements which differ significantly from conditions prevailing on bare ground. Climax species are not early invaders and often cannot even be planted on barren sites. Table 3-2 is based on estimates of recovery times following various treatments and gives Recovery Indices. The ranges of time for expected recovery are quite large because the factors which affect them (e.g., soil factors, precipitation cycles, etc.) have potentially greater impact on recovery times than do the differences between the impacts of various cleanup treatments. Consequently, while deep plowing (1-6) has a greater perceived impact than shallow plowing (1-5), for example, the seres are sufficiently long and local variability is sufficiently great that climax recovery times cannot be effectively differentiated.

Minimum time to recovery of climax appears to be around a century. That is the time required to pass through the various seral stages and create microclimatic conditions favorable to climax species. The exception is where the trees were clearcut but the forest was otherwise not disturbed (1-2). Sprouting may result in more rapid recovery, but even that is limited by the growth rate of the trees and the degree of invasion by non-climax species. Treatments 1-3, 1-4, 1-5, and 1-6 all require a full sere and the local variability is probably greater than the differences between them. Shallow soil cover (1-7) and shallow soil removal (2-1) may result in conditions similar to the above (optimally) or could possibly be more severe perturbations. If unassisted, natural revegetation is possible, time to climax should be similar to the above. If not, reclamation may be indicated.

Reclamation might be necessary where depth of soil applied is great (1-8) or the depth of soil removed is great (2-2), even if stabilizers are used (2-5, 2-8). If not reclaimed, decades could be added to the recovery times. With reclamation, time to climax should be within the range of natural seres on more favorable sites (1-3, 1-4, 1-5, 1-6). In general, stabilizers (2-3, 2-4, 2-5, 2-6, 2-7, 2-8) would be expected to greatly influence early succession but their effects would not be expected to be discernible by the time climax is approached.

Hard-surface stabilization (4-1, 4-2) would significantly retard the onset of succession and lengthen the potential minimum time for recovery. It is not clear if any effect would be discernible on a sere requiring 200 or more years.

Barriers (3-1, 3-2, 3-3) do not disturb vegetation in the system and have no recovery time associated with them. Wildlife is discussed in Part III.

3.7 CONCLUSIONS

The preferred treatment is the "no action" option of erecting barriers (3-1, 3-2, 3-3). The advantage is that it allows time for careful evaluation of what further steps might really be required. Particularly where large areas might be contaminated, the effectiveness and impact of other treatments could be evaluated experimentally.

Hard-surface stabilization offers no apparent benefits and should not be considered.

As a generality, there are no significant advantages or disadvantages obviously associated with any of the other treatments. The decision to actively reclaim or not will be influenced by the area disturbed and location. A small (0.01 km^2), isolated area might not need to be reclaimed while a similar area having significant population exposure probably would need to be. Any 10.0 km^2 area disturbed would probably require reclamation of some kind. Beyond these considerations, local experience with road and other construction will influence decisions on need for stabilizers and/or reclamation.

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CHAPTER 4
CONIFEROUS FORESTS

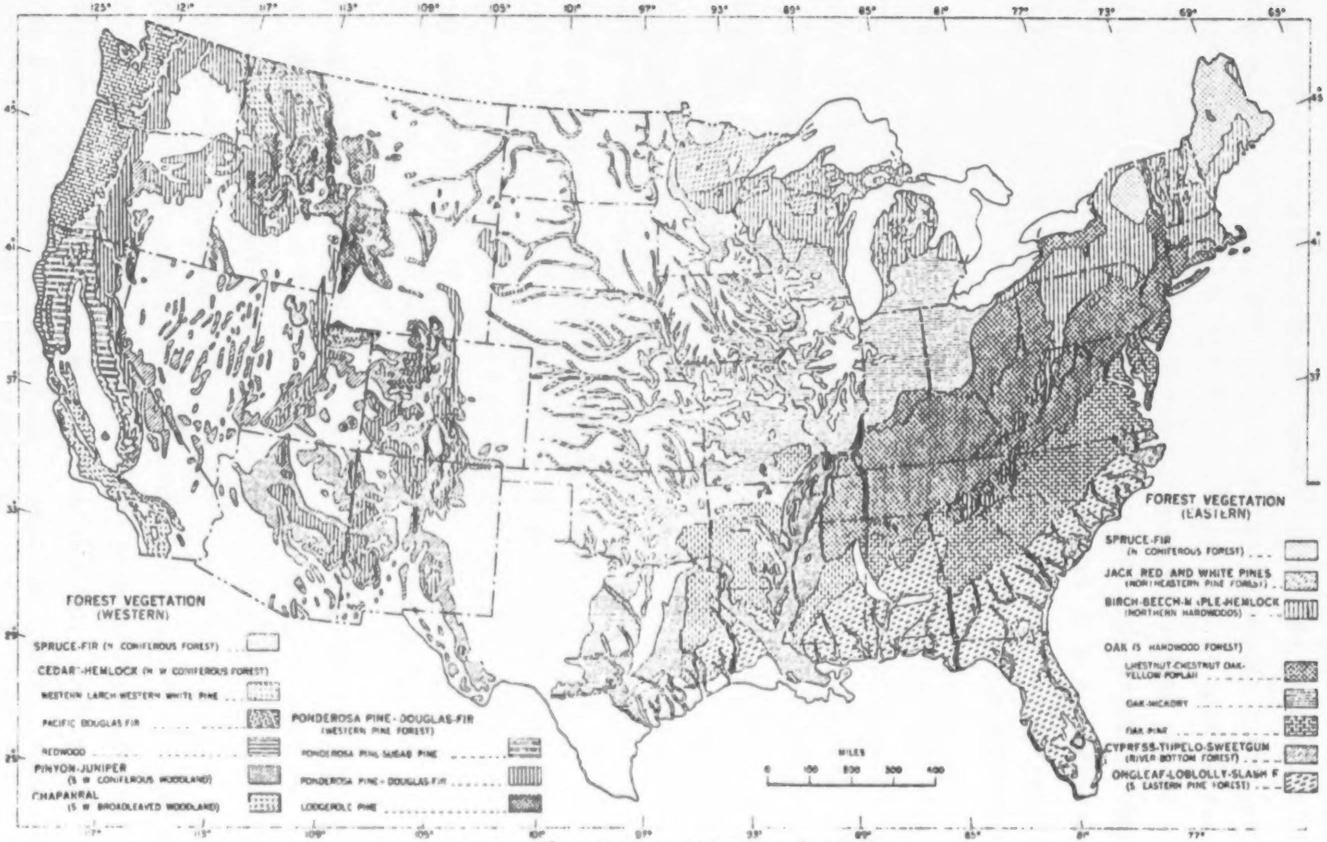
4.1 OVERVIEW

The coniferous forests of the United States occur in all sections of the Nation except for the Great Plains. In the eastern portion of the country, the distribution of conifers is considerably more continuous and less complex than in the mountain and far western states. In the East, zonation tends to be primarily a function of latitude, while in the West, altitude and slope aspect become major factors. In the East, it is likely that cleanup procedures would be limited to a single forest type, but in the West, one or more zones may be involved if a spill occurs in a mountainous area. It is not possible to consider the coniferous forests apart from mountainous regions, so both will be discussed here, as will the interface between the coniferous and tundra zones. The primary purpose of the first section of this Chapter is to provide a relatively detailed overview of the major types of coniferous forest in the United States with respect to their distribution and major species associations.

Oosting[51] has reviewed the climax vegetation types of North America and notes that there is considerable variation among vegetation maps with regard to detail due to disagreement on the interpretations of climax relationships. Examples of such vegetation maps may be found[58,63,29]. More recent maps have been published by Little[42] and Kuchler[38]. Oosting[51] believes that studies of local investigations of vegetation are necessary for a comprehensive understanding of the bases for the differing interpretations found on vegetation maps. This statement is no doubt also applicable to most descriptions of the distribution of coniferous forest types, particularly those found in the more diverse mountainous areas of the country. It is also important to note that forest types change in many areas due to shifts in land use and in natural succession processes, dating older maps. For example, the harvesting of Douglas fir has resulted in the replacement of large stands of that tree by western hemlock and various hardwoods with a resultant net increase of western hardwood forest types of nearly two million acres in the period of 1962-1970[77]. The concept of vegetational climax formations and their associations permits classification on a regional basis; it assumes an acceptance of monoclimax theory which implies the existence of pre and postclimax communities. While this system is dated, it has been widely used in various forms in the literature on North American vegetation and it will provide a basis for the following description of the coniferous forests of the United States.

The coniferous forest has been divided into four climax formations in North America: Boreal, Subalpine, Montane, and Pacific Coastal. There are also large areas of coniferous forest that are considered to be sub or postclimax by this system. Oosting[51] has characterized the nature and distribution of these formations in some detail and the following descriptions are largely adapted from his work. Another system of nomenclature refers by the major species associations and/or their geographical location: northern coniferous forest (spruce—fir); northwestern coniferous forest (cedar—hemlock, western larch—western white pine, Pacific Douglas fir—redwood); western pine forest (ponderosa pine—sugar pine, ponderosa—Douglas fir, lodgepole pine); northeastern pine forest (Jack, red and white pines); and southeastern pine forest (longleaf, loblolly, and slash pines). (See Figure 4-1.)

The Boreal is the most continuous of the major forest formations with respect to distribution. In the western United States, the various coniferous formations appear in vegetation zones which occur as a function of altitude and size of a mountain mass, the latter affecting the quantity of precipitation which will occur on a given mountain range. At a given latitude, an isolated mountain peak may not support stands of species having high moisture requirements that may be satisfied on a nearby mountain range of lower elevation but greater mass. Due to the prevailing winds from the west, significant vegetation differences occur between the western and eastern slopes of the mountain ranges. The character of the communities within a given zone also differs among mountain ranges. The Rocky Mountain and Sierra Nevada forest complexes differ significantly and are discussed separately here. The zonal climaxes occurring within these complexes include: Tundra, Subalpine, Montane, and Foothill (not discussed).


FOREST VEGETATION (WESTERN)
SPRUCE-FIR (N. CONIFEROUS FOREST)
CEDAR-HEMLOCK (N. W. CONIFEROUS FOREST)
WESTERN LARCH-WESTERN WHITE PINE
PACIFIC DOUGLAS FIR
REDWOOD
PINYON-JUNIPER (S. W. CONIFEROUS WOODLAND)
CHAPARRAL (S. W. BROADLEAVED WOODLAND)
PONDEROSA PINE-DOUGLAS-FIR (WESTERN PINE FOREST)
PONDEROSA PINE-SUGAR PINE
PONDEROSA PINE-DOUGLAS FIR
LODGEPOLE PINE
FOREST VEGETATION (EASTERN)
SPRUCE-FIR (N. CONIFEROUS FOREST)
JACK RED AND WHITE PINES (NORTHEASTERN PINE FOREST)
BIRCH-BEECH-MAPLE-HEMLOCK (NORTHERN HARDWOODS)
OAK (S. HARDWOOD FOREST)
CHESTNUT-CHESTNUT OAK-YELLOW POPLAR
OAK-HICKORY
OAK-PINE
CYPRESS-TUPELO-SWEETGUM (RIVER BOTTOM FOREST)
LONGLEAF-LOBLOLLY-SLASH F (S. EASTERN PINE FOREST)
MILES
0
100
200
300
400
125°
121°
117°
113°
109°
105°
101°
97°
93°
89°
85°
81°
77°
73°
69°
65°
45°
41°
37°
33°
29°
25°

(Courtesy of the U.S. Forest Service.)

Figure 4-1. Natural forest vegetation of the United States (adapted from Sharpe, Hendee and Allen[59]).

4.1.1 Boreal Formation

The Boreal formation, sometimes referred to as "taiga" in its northern areas, forms a broad band across the North American continent, lying to the south of the Tundra formation; it occurs as far south as the New England states. The climate in the Boreal forest region is almost as severe as that of the Tundra, being characterized by a cool, short growing season and moderate precipitation that is heaviest near the East Coast (approximately 40 inches) and lightest in the western region and the Alaskan interior (10 to 12 inches). The topography characteristic of the Boreal formation is largely the result of glaciation and abounds with lakes, bogs, and muskegs. Thin residual soils overlay rock masses, or deep moraine and outwash occur along the southern boundary of the formation.

The Boreal formation is characterized by climax growth of white spruce (Picea glauca) and balsam fir (Abies balsamea); this climax is best developed along the St. Lawrence River Valley. White spruce and balsam fir are found scattered throughout the range and they are associated with paper birch (Betula papyrifera) which may occur following fires in pure stands as a subclimax. Black spruce (Picea mariana) is frequently dominant north and west of Lake Superior, and it is frequently found associated with tamarac (Larix laricina) as climax species along the northern and far western transitions in high rocky areas. Further to the south, both species become associated with bogs. To the west, paper birch and Jack pine (Pinus banksiana) occur as climax species, and are subclimax nearer the center of the Boreal formation. Jack pine and black spruce form a subclimax in the western part of the range and Jack pine also occurs extensively in areas of sand plains and gravel soils.

The northern transition of the Boreal formation into the Tundra is irregular with the coniferous forest extending far into the Tundra region in sheltered valleys while the Tundra is found on high ridges extending into the forested area. Indications were found by Griggs[26], who studied the reasons underlying the positioning of the Arctic timberline, which suggested that the timber line in Alaska is advancing northward while it is retreating in portions of Canada. The southern transition grades into grassland in the west and into deciduous forest in the east. Also, in Alaska, the Boreal coniferous forest merges with the northwestern coastal forest. The southern Boreal transition zone is marked by pure stands of white pine (Pinus strobus) from New England to Minnesota and

and red pine (Pinus resinosa) in the Lake States; Jack pine also occurs in less favorable sites in the Lake States area. In the eastern transition, spruce and fir may mix with hardwoods or grow in alternating stands. In the Rockies, Picea glauca is associated with Abies lasiocarpa. The northern coniferous forest extends southward on the higher Appalachian mountains as far as the Great Smoky Mountains of North Carolina. There, the growth form and species associations are similar to those found throughout the Boreal formation, but red spruce (Picea rubens) tends to replace white spruce from New Brunswick southward into New England. Further south, balsam fir is replaced by Fraser fir (Abies fraseri). Therefore, the dominant species in the southern Appalachians are the ecological equivalents of those found elsewhere in the Boreal formation, but they may be distinguished taxonomically. As the latitude decreases, the spruce-fir forest is limited to increasingly higher elevations; this association may be found virtually anywhere in the northern portions of the Boreal formation, but only above approximately 5,000 feet in the Great Smoky Mountains. Spruce tends not to occur at the highest altitudes in the southern range and, in its absence, fir becomes dominant[51].

4.1.2 Rocky Mountain Forest Complex

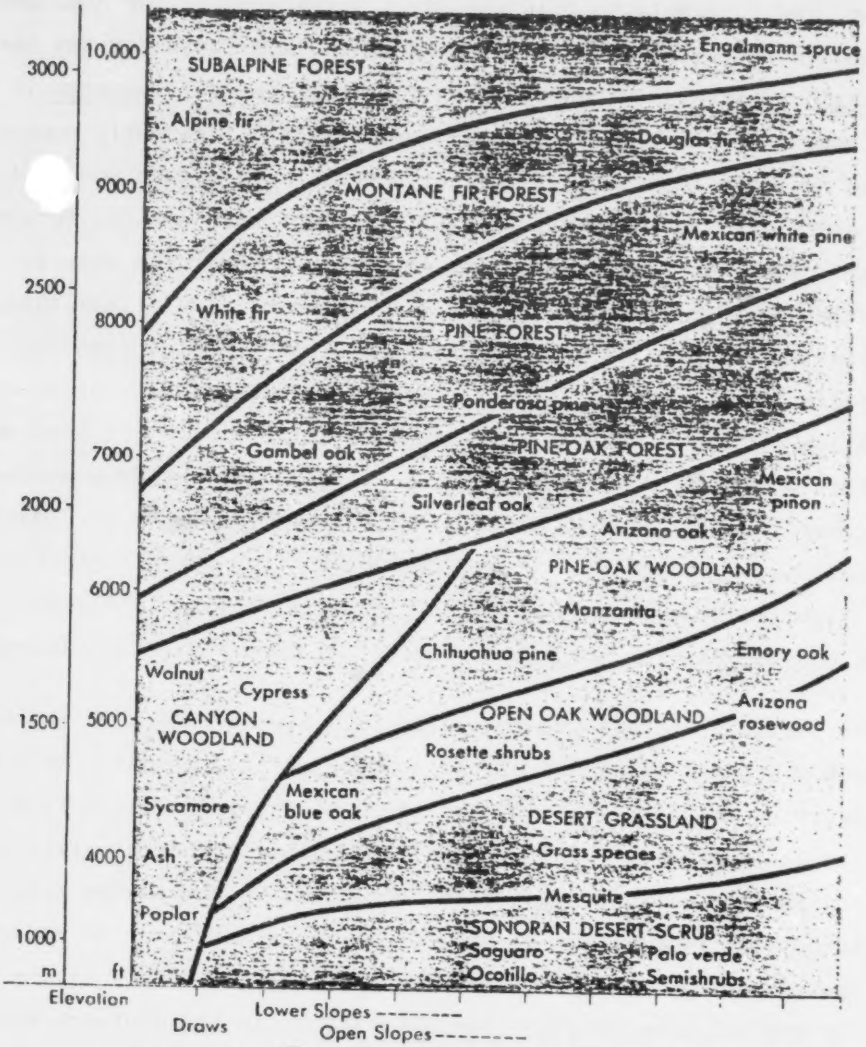
The Rocky Mountain forest complex contains several distinguishable vegetation zones that extend as far north as Alberta and southward into northern Mexico, terminating at the southern end of the Sierra Madre range; this zonation extends westward to the eastern foothills of the Sierra Nevada range and the eastern slopes of the Cascades, it also extends eastward into the Black Hills. In addition to the major Rocky Mountain Ranges, the complex encompasses the basin and range physiographic province with its numerous north-south ranges separated by desert basins. The zones that occur are a discontinuous alpine zone on the higher peaks, subalpine, montane and woodland forest. These zones are discontinuous in their distribution from range to range and the full complement of zones is not necessarily present in each of the ranges. For example, in the northern portion of the complex, the upper zones exist at lower altitudes and the lower zones may not be present; each zone occurs at increasing elevation as the latitude decreases. As previously discussed, there are significant differences in zonation between north and south exposures and there are marked differences in vegetation between the eastern and western slopes of the individual ranges within the system and for the entire system as a whole.

In mountain systems, narrow valleys tend to allow the dominants of a given zone to extend downward into a lower zone while high dry ridges permit upward finger-like projections of the dominants into continuous higher zones. Drainage of cold from higher elevations can significantly disrupt zonal distribution patterns.[51] Whittaker and Niering[83] have detailed the effects of altitude and slope aspect upon vegetation in the Santa Catalina Mountains of southern Arizona. (See Figure 4-2.) A review and synthesis of the factors which produce and control the zonation of the vegetation in the Rocky Mountains by Daubenmire[15] may be of particular interest in the determination of the probability of reestablishing forest growth after implementation of cleanup procedures.

The zonal climaxes which occur within the Rocky Mountain coniferous forest complex have been grouped by Oosting[51] as follows:

- Alpine zone
    - Tundra climax
- Subalpine zone
    - Engelmann spruce—Alpine fir climax
- Montain zone
    - Douglas fir climax
    - Ponderosa pine climax
- Foothills (Woodland zone)
    - Piñon—Juniper climax
    - Oak—Mountain Mahogany climax

The vertical range of full development of each of the zones is approximately 2,000 feet, with the foothill zone narrowing and disappearing at the higher latitudes and each of the other zones being found at progressively lower altitudes. In the transitions between the zones, the species characteristic of each zone become restricted to favorable habitats. Near the upper boundary, these species will be more common on ridges and south-facing slopes where less moisture and higher temperatures occur; whereas in the lower transition, the species characteristic of a given zone will tend to occur in the relatively cool, moist sites. Under these conditions, species of one zone may extend into another zone. Precipitation tends to increase with altitude; a linear increase of 4.94 per 1,000 feet of elevation was found between the sagebrush and alpine zones on the Wasatch Plateau of Utah[45] and Oosting[51] notes that similar observations have been made elsewhere.



Vegetation chart for the Santa Catalina Mountains, southeastern Arizona. (The pattern above 9000 ft is for the nearby Pinaleno Mountains.) Four hundred vegetation samples were plotted on the chart by their positions in relation to the elevation gradient, on the left, and the topographic moisture gradient, on the bottom. Boundary lines were drawn to connect the mean positions at which one community-type, as these had been defined in this study, gave way to another. Dominant species are indicated in the parts of the pattern where they are most important. [Whittaker and Niering, 1965.]

Figure 4-2. Vegetation chart for the Santa Catalina Mountains, southeastern Arizona (reproduced from Whittaker[82]).

4.1.2.1 Subalpine Spruce-Fir Climax --

Engelmann spruce (*Picea engelmannii*) and alpine fir (*Abies lasiocarpa*) are dominant in the subalpine zone. The spruce tends to be larger, more abundant, and longer-lived than the fir. Variations in the dominant species are found in different regions. For example, in Arizona and New Mexico, *Abies lasiocarpa* var. *arizonica* is as important as *A. lasiocarpa* is in other ranges, while mountain hemlock (*Tsuga mertensiana*) frequently occurs in Montana and northern Idaho; still further north, *Picea glauca* and *A. lasiocarpa* may be associated as the transition with the northern conifer forest is approached. There is more variability among the subordinate species found in the Rockies than among the dominants. In the subalpine climax zone, lodgepole pine (*Pinus contorta* var. *Murrayana*), aspen (*Populus tremuloides*), and Douglas fir (*Pseudotsuga menziesii*) occur as climax stands following burns; restoration of the original climax stand is quite slow. The same situation may obtain following cleanup procedures. Lodgepole pine does not occur in the southern Rockies, and in other areas, aspen frequently predominates over the pine. Aspen has the ability to regenerate from sprouts and this may provide a significant advantage over the pine after a burn. This factor should also be considered with respect to forest regeneration after cleanup.

The subalpine forest grades gently into alpine tundra in the transition zone with a gradual lessening of the density of tree stands. Near the timber line, dwarfing and distortion of the trees occur, producing a tree form referred to as "Kummholz." The timber line region is characterized by certain tree species that are not adapted to conditions in the tundra zone and which are unsuccessful competitors in the climax forest at lower elevations. However, these species do occur on dry and windy ridges. This is the niche occupied by the bristlecone pine (*Pinus aristata*) in the southern Rockies, limber pine (*P. flexilis*) in the central Rockies, whitebark pine (*P. albicaulis*), and alpine larch (*Larix lyallii*) in the northern Rockies, with the exception of the far northern areas where lodgepole pine is found at the timber line.

4.1.2.2 Douglas Fir Climax --

The Douglas fir climax zone lies at altitudes just below the subalpine spruce-fir zone. Douglas fir characteristically occurs in such density that few subordinate species are present. There are north-south differences in the Douglas fir forest. In the south, white fir (*Abies concolor*) and blue spruce (Picea pungens) are present, but they are restricted to relatively small damp sites. In the north, the subclimax species present differ with respect to the direction of the slope face and the relationship of the site to the continental divide. Grand fir (Abies grandis) is found west of the divide and characteristically occurs on the western slopes. East of the divide Picea glauca, a representative of the northern conifer forest, exhibits its codominance with Douglas fir, and is found southward through the montane zone into the Black Hills.

On exposed ridges, open stands of pine which include species characteristic of timber line are found both in the montane and subalpine zones. The species found differ with the region: P. fliexelis var. reflexa is found in the south; P. aristata occurs in northern Arizona, southern Utah and Colorado; and P. flexilis occurs northward to the point where it is replaced by P. albicaulis.

When stands of Douglas fir climax forest are burned, lodgepole pine or aspen replace it, exhibiting the same relationships as discussed for the subalpine zone.

4.1.2.3 Ponderosa Pine Climax --

Just below the altitude of the Douglas fir belt is the Ponderosa pine (Pinus ponderosa) zone. This species and its close relatives occur in relatively open forest that becomes increasingly like savannah as the altitude decreases. Due to the open structure of the growth, grasses form a ground cover. The Ponderosa climax is separated from the Douglas fir by a rather broad transition where both species coexist in a shared dominance relationship. The term Ponderosa climax is something of a misnomer as that species is truly dominant only in the northern Rockies west of the continental divide. In other regions, Ponderosa is replaced by or found in association with closely related varieties, having similar ecological characteristics such as P. ponderosa var. scopulorum on eastern slopes in the north; throughout the zone southward, P. ponderosa var. arizonica, P. leiphylla var. chichuahana, and P. contorta var. latifolia, all occur in the southern Rockies. Along streams and drainage lines, narrow leak cottonwood (Populus augustifolia) will form postclimax stands with P. acuminata and P. sargentii. Aspen (P. tremuloides) and box elder (Acernegundo) may also occur in moist areas.

Older Ponderosa trees are somewhat resistant to fire and are killed only by severe burns. Pondersoa seedlings are destroyed and saplings tend to occur in the understory in groupings of even age, representing growth of several consecutive fire-free years. Severe fires may result in stands of lodgepole pine, while lumbering and overgrazing may result in dense growth of scrub species found in the oak-mountain mahogany zone.

4.1.2.4 Piñon-Juniper Climax --

The lowest of the Rocky Mountain coniferous zones is characterized by the piñon-juniper climax. Typically, this is a zone of open vegetation with small trees from 10 to 30 feet in height. This vegetation zone also occurs on many of the low ranges in the Great Basin as the only zone present. The piñon-juniper climax is typical of the intermountain region and forms a distinct zone in the southern Rockies[84]. The appearance and characteristics of the vegetation within the piñon-juniper zone are relatively constant, although it includes several species with restricted ranges and marked regional differences with respect to taxonomic and sociologic considerations occur. Among the junipers present in the zone are *Juniperus scopulorum*, *J. osteosperma*, *J. monosperma*, *J. occidentalis*, *J. deppeana* (this list is not all-inclusive); the piñons, or nut pines, are variously referred to as species or varieties and include *Pinus cembroides* (*P. edulis*, *P. monophylla*, and *P. quadrifolia*).

This climax zone extends from northern Mexico along the western slope of the Rockies to the Snake River in Idaho and into southern Alberta with the piñon while the desert species of Juniper are replaced by *J. occidentalis* or *J. scopulorum*. On the eastern slope of the Rockies, the zone extends as far as Fort Collins, Colorado, at which point piñon disappears and *J. scopulorum* continues northward through Wyoming, frequently associated with sagebrush. In the northern Sierras, piñon-juniper is not present with Jeffrey pine (*Pinus Jeffreyi*) grading directly into *Artemisia* and *Pushia*; it does exist on the low eastern slopes of the southern Sierras but tends to occur in mixed growth with other species. However, piñon-juniper does occur on every westernmost range and mountain of the Great Basin, and frequently is separated from the Sierra Nevada range by only a single valley.

4.1.3 Sierra Nevada Forest Complex

The following discussion of the Sierra Nevada Forest Complex will include the southern Cascade Mountains and the Sierra Nevada which extend from Oregon southward along the California-Nevada border, including the innermost ranges of the coastal mountain system. The western slope of the Sierras is gradual while the eastern slope is quite abrupt, dropping from peaks of more than 14,000 feet to the floor of the Great Basin at an elevation of approximately 4,000 feet. Due to this slope difference, the western slope encompasses a much greater land area than does the eastern.

4.1.3.1. Western Slope --

Due to the north-south axis of the Sierras, and the prevailing westerly winds, the eastern slopes of the range are much drier than the western. At the base of the western slopes, 10 to 15 inches of precipitation fall annually with a long, unbroken summer dry season. As the altitude increases, the dry season shortens, temperatures fall, and precipitation increases with a greater proportion falling as snow. Approximately 80 to 85 percent of the precipitation occurs in the winter, with 35 to 75 feet of snow falling in the subalpine zone. The heaviest total precipitation is reported to occur between 5,000 and 7,000 feet[41] where the mixed coniferous forest of the montane zone is found. The subalpine zone coincides with that zone having the greatest snowfall, and possibly this is the zone of greatest precipitation since snow gauges which are exposed to high winds tend to give low readings; spring snow surveys indicate a greater water content of the accumulated snow than can be accounted for by reported precipitation[36]. This fact may have implications for cleanup procedures.

Subalpine Zone — The subalpine zone is usually found in a 1,000-foot vertical range between 6,500 and 9,500 feet depending upon the latitude. Typically, this zone experiences cool, short growing seasons with wet winters and dry summers.

The major climax species found in the subalpine zone in the Sierra Nevadas is red fir (*Abies magnifica*), which comprises 80 to 90 percent of the forest tree growth, occurring in dense stands. Other species are associated, but of minor importance in the climax growth. Western white pine (*Pinus monticola*) is usually present as a minor constituent. Lodgepole pine (*Pinus contorta*) is often present, at the edges of meadows, but in a successional role. Irregular growth of mountain hemlock (Tsuga mertensiana) and white fir is found in the zone, with the former tending to occur at the higher elevations of the zone and the latter at lower elevations. Shrubs and herbs are found throughout the zone and lichens occur on the trees.

Timber line is often found at lower elevations in the Sierras than in the Rockies, ranging from 7,000 to 10,000 feet depending upon the latitude; this is due to the more severe environmental conditions occurring in the Sierras. Pinus albicaulis, P. flexilis, and P. balfouriana are characteristic of timber line growth in the Sierras[65]. Juniperus occidentalis is also common at timber line on exposed, rocky slopes; it is also found on the western slopes at lower altitudes. Generally, red fir growth does not extend to timber line, but instead grades into a relatively narrow band of Pinus contorta - Tsuga mertensiana dominance. In this zone, P. contorta assumes a climax role, although it is successional to Abies magnifica at lower altitudes; hemlock also has climax characteristics at the upper limits of the subalpine zone.

Montane Zone—The montane zone occurs between 2,000 and 6,000 feet in the Cascades, between 4,000 and 7,000 feet in the central Sierras, and between 5,000 and 8,000 feet or more in the south. Five or six principal species have climax characteristics in this zone and tend to occur in any combination at any altitude, although the upper and lower margins of the zone are likely to have consistent vegetational differences. In the upper part of the zone, white fir is usually the important dominant, where it is sometimes found in pure stands; its numbers decrease at lower elevations. Important species at lower elevations include sugar pine (P. lambertinana), Jeffrey pine, Ponderosa pine, Douglas fir, and incense cedar which tends to predominate on the most favorable sites. Douglas fir is more frequent in the north; sugar pine and Jeffrey pine are more abundant at higher elevations, the latter being the most drought-resistant of the major species of the zone.

4.1.3.2 Eastern Slope --

The eastern slope of the Sierra Nevada range has the same vegetational zones as those found on the western slopes. However, the abruptness of the eastern slope and its drier climate result in less favorable conditions and some differences in the distribution of vegetation from that found on the western side. The red fir forest is found in restricted areas such as the Carson Range east of Lake Tahoe and in localized areas in the northern Sierras. The subalpine zone is generally represented by patches of lodgepole pine and those species of pine found at timber line on the western side. The montane zone extends to high altitudes with poorly developed vegetation. In this zone, Jeffrey pine is the most important species and it occurs in open stands which differ in appearance from those on the western slope. Piñon-juniper forest is restricted to a few eastward-extending high spurs of the range, although it is well developed on the next range to the east of the Sierras[51].

4.1.4 Pacific Conifer Forest

The coniferous forests of the Pacific coastal region parallel the coast from the timber line in Alaska southward to central California. Mountain ranges of various altitudes are found within the range of this forest type. The entire region from north to south is characterized by a mild climate which is tempered by the presence of the Pacific Ocean. Subzero temperatures are rare on the Alaskan coastline and from Oregon southward, frosts are rare. Precipitation ranges from 30 to 150 inches and the humidity tends to remain high. In the south, rainless summers tend to be compensated for by fog. Snowfall increases with latitude where 50 to 60 feet may occur in some of the higher mountain ranges in the north.

The character of the coastal forest is primarily montane throughout its altitude range from 0 to 5,000 feet. In the northern portion of the Cascades in the Washington-British Columbia border region, some subalpine forest occurs, but it contains dominant species derived from the Rocky Mountains (Abies lasiocarpa), the Sierra Nevadas (Tsuga mertensiana) and the coastal forest (Abies amabilis and A. procera). Tundra exists on some of the higher mountain peaks.

The best development of coastal forest species occurs in the general vicinity of Puget Sound, with the most luxuriant vegetation occurring in the rain forest of the Olympic Peninsula where the ranges of all of the major species overlap and most of the trees attain their maximum size. The climax dominants are western hemlock (Tsuga heterophylla), western arborvitae (Thuja plicata) and grand fir (Abies grandis). Douglas fir is the most abundant and widespread species; it tends to be found in the drier sites. It is intolerant of shade and becomes the major dominant after fires and is therefore subclimactic in its relation to the forest.

North of Puget Sound, sitka spruce (Picea sitchensis) becomes increasingly abundant and is a climax dominant along with Tsuga heterophylla and T. mertensiana in the northern extension of the forest. In Alaska, where the Boreal and Coastal forests interface with the tundra, P. sitchensis and P. glauca occur at timber line. Southward from Puget Sound, Douglas fir becomes increasingly important and Port Orford cedar (Chamaecyparis lawsoniana) becomes an added climax species. Along the coast, redwood (Sequoia sempervirens) replaces Sitka spruce. The redwoods are generally limited to the fog belt and their range extends irregularly for a number of miles south of Monterey, California. The species of the coastal forest extend eastward along the Washington-British Columbia border, expanding to the north and to the south on the western slop of the Rockies. Species found in this extension include Tsuga heterophylla, Thuja plicata, and Pseudotsuga mensiesii and occupy a zonal position between the Douglas fir and spruce fir zones of the Rockies. Western larch, white pine, and grand fir also occur in this extension. Daubenmire[6] noted that this extension follows a well developed storm track and is frequented by winds which blow eastward from the coast[51].

4.1.5 Coniferous Forests Occurring as Sub and Postclimaxes

Extensive coniferous forests occur in the eastern portion of the Nation as subclimaxes which are maintained by fires or swamps; in some regions these forests are not considered to be climaxes. The coastal plain from New Jersey to Florida and along the Gulf States into Texas is a relatively flat area at low altitude. The soil is generally sandy and tends to have poor drainage with many swamps. Raised areas are usually dry for a portion of the year. Dry seasons are accompanied by low water tables and relatively frequent fires. In New Jersey, pitch pine forests occur and loblolly and slash pine are found in the states further south. These pine forests are generally open with grass floors and are referred to as savannahs. Frequent grass fires permit survival of the relatively fire-resistant conifers at the expense of oak and hickory, which would replace the conifers if the area were given prolonged protection from fire[81,12]. Some consider these areas to be a "pyric climax." Whatever terminology is used, the presence of frequent fires in such areas must be considered in the reestablishment of the original growth that preceded cleanup procedures.

Coniferous forest may also be encountered within those regions generally dominated by hardwoods. Also, an association of hemlock and hardwoods occurs in the transition between the northern coniferous forest and the deciduous forest. Hemlock (Tsuga canadensis) frequently occurs with beech and sugar maple and less frequently with birch, white pine, and other hardwood species from northwestern Minnesota through the Lake States into Nova Scotia. Many pure stands of pines (P. strobus and P. resinosa) have been destroyed by fire and lumbering. White pine is found within the hardwood climax forests of the region, but Oosting[51] believes that these long-lived trees should be considered as relicts, although they do reproduce in open areas in the hardwood forest. As such, their replacement following cleanup procedures may prove to be difficult and might be considered to be optional, depending upon local circumstances. Tamarack, black spruce, and white cedar (Thuja occidentalis) occur in postclimax stands and occupy bogs throughout the region. Aspen and pine also occur in burned or logged out areas.

Pitch pine (P. regida), Virginia pine (P. viginiana) and shortleaf pine (P. echinata) occur from southern New England to Georgia in that region frequented by an association of oak and chestnut, with the latter two species becoming locally abundant in the southern part of the range. In the south, the occurrence tends to be limited to higher altitudes, but in the north, it occurs at lower elevation and occurs as far east as Long Island. Virginia pine, shortleaf pine and loblolly pine also occur on abandoned land throughout the region of the oak-hickory association on the Piedmont Plateau and on the coastal plain of the Atlantic and Gulf States. Virginia pine predominates in the northern Piedmont with shortleaf and loblolly pine preceding climax growth in the south, usually occurring in pure stands.

4.2 NATURAL PERTURBATIONS

4.2.1 Fire

4.2.1.1 Unassisted Recovery Sequence --

Fossil records indicate that fire has probably always been a part of the environment of forests on the surface of the earth. Most of the species of conifers have a number of fire-adapted regenerative qualities which range from a need for mineral seed beds to a requirement for high temperatures to permit the opening of serotinous cones. Thick bark, adventitious buds, and coppice sprouting also enhance survival of fire. Most coniferous species are also tolerant of exposure to sunlight and open space[37]. It seems likely that many of these fire-adaptive qualities will serve to assist the recovery of the coniferous forest from cleanup procedures, if those procedures are significantly more disruptive of the forest than would be a severe fire. However, it is important to note that these characteristics are not universal among coniferous trees.

On a study plot in the Sierra Nevada mountains, which was established after a severe fire in 1960, it was found that natural revegetation (unassisted) by Jeffrey pine seedlings greatly exceeded that by fir seedlings[8]. This situation was reversed in data obtained from ten unburned control plots where establishment and growth of fir seedlings exceeded the pine seedlings. The pine seedlings were found to have high survival rates and demonstrated an exponential rate of growth. Some of the trees had attained heights of 250 cm at fourteen years of age (having germinated the summer of the burn). It was also noted that pine seedling recruitment occurred at approximately identical rates on burned and unburned plots.

The sequence of events following a severe forest fire will differ for each particular forest and location within that forest. It is difficult to generalize in this regard for all of the coniferous forests of North America. At the site of the Donner Ridge test plots, the natural postfire reforestation pattern appears to be: pine > pine + fir > fir.[7] However, the stage of pure fir forest is seldom reached in the region due to interference by fire, and Bock et al.[8] note that it is difficult for this fire-regulated successional pattern to be reconciled in terms of classical ecological climax community classifications[8]. Bock et al.[8] suggest that Jeffrey pine is particularly adapted to the fire environment, since the observed sustained exponential growth pattern would not be expected in the irregular climatic conditions that have obtained in recent years in that area.

Following a forest fire, the successional pattern is reset. Fungi and other microorganisms invade the area[62], and the composition of wildlife populations is altered due to the drastic alterations in habitats produced by the fire. Lyon and Stickney[46] have examined the vegetal succession that follows large fires in the northern Rocky Mountains. They found that succession in the forest is not an autogenic process in which initial seral plants modify the site to their own exclusion and then subsequently permit the establishment of interseral and eventually climax species. Instead, they note that succession is a sequential development of vegetation in which the more rapidly maturing and often shade intolerant plants assume initial dominance and then in turn are dominated by taller, slower growing, and often more shade tolerant species. They obtained data from three large wildfire burns that indicated that a high percentage of plant species on a site at the time of the fire survive and reestablish themselves on the burned area. The majority of recognizable survival adaptations are on-site plant parts and seeds or fruits, and these provide the major source of early seral vegetation. They noted an exception to this rule in a few species that have both an on-site survival mechanism and airborne seeds. They found that all of the dominants of early succession will be established in the initial postfire growing season, whether or not they are derived from on- or off-site sources. Lyon and Stickney[46] believe that reliable estimates of the likely composition of the early successional forest can be derived from the composition of the prefire or the first postfire year communities. Further predictions may be possible based upon the survival strategies and dominance potentials of the various plant species in the community which will indicate the probable structural configurations of the early successional period.

The findings of Lyon and Stickney[46] suggest that in many areas, the probable course of unassisted recovery from a cleanup operation in a coniferous forest might be predicted on the basis of local data on fire recovery.

4.2.1.2 Assisted Recovery Sequence --

Shearer[64] has compared the effects of unassisted fire recovery with assisted recovery in coniferous forests in the Rocky Mountains. He notes that historically coniferous forests of the northern Rockies have been returned to early stages of succession by fire[39]. This is largely a consequence of heavy accumulations of litter and other flammable debris accumulated over many years. Pioneer species such as western larch (Larix occidentalis) and lodgepole pine (Pinus contorta) require an early successional stage, and they rarely become established in the absence of a major disturbance of forest. Frequently, land managers utilize mechanical scarification on slopes of less than 30 percent in order to enhance the formation of a seed bed. Shearer[66] describes experiments designed to obtain quantitative data concerning the effects of varying intensities of burning on natural regeneration in western larch/Douglas fir forest. It was found that early establishment of coniferous forest regeneration following prescribed broadcast burning of clearcuts was influenced by the interaction of several factors, the most important of which were (1) seed bed condition, (2) seed supply, and (3) environmental characteristics affecting seedling survival.

Shearer[60] noted that even under the most extreme conditions of fire, the soil temperature remained at 66°C at a depth of 29 mm while the surface temperature was 260°C; therefore, the underground systems of the plants receive relatively little damage, and most species were able to reestablish themselves by vegetative reproduction.

It was observed that most of the seeds that fell on the clearcuts came from adjacent growth, although some were from unidentified sources, perhaps miles distant. Most of the natural seeding occurred during periods of turbulence associated with frontal weather systems. The actual distribution of the seeds on the large clearcuts decreased rapidly with increased distance from the edge of the adjacent timber stand surrounding the burn, but there was a low, relatively constant concentration of seeds throughout the central section of the burned area. Possibly a higher proportion of the total seed in the central area was derived from unidentified distant sources, rather than from the adjacent timber stand.

Germination of seeds was adequate on treated and untreated seedbeds, but was greater on bare mineral soil (burned or scarified) than on scorched or unburned duff. It was found that germination began sooner on clearcut test beds possibly due to higher soil temperatures than obtained beneath residual timber. It was also found that the establishment of seedlings could be increased by burning the residual duff on clearcuts. Burned clearcuts facing from 300 degrees to 90 degrees azimuth (west-northwest to east) regenerated well. Clearcuts with the least amount of regrowth were judged to have poor seed sources. Regeneration was reduced on less favorable aspects where high surface temperatures and low soil water limited seedling establishment. Smaller burned areas having three or four adjacent timber edges tended to have increased regeneration due to a better seed supply and possibly better shading from the adjacent forest.

Shearer[60] also notes that successful regeneration was so strongly associated with the type of habitat. Growth was particularly successful under shade cast by either living or dead trees on burned seedbed. Growth was sparse on poorly burned seedbeds and on hot open slopes with little or no shade. In general, moist habitats regenerated well, while drier areas were understocked. Large clearcuts received insufficient seed fall and the upper soil was soon depleted of available water by heavy vegetative competition.

Shearer[60] concluded that clearcutting coupled with prescribed broadcast burning on north- and east-facing slopes usually leaves the cutover area receptive to natural regeneration if sufficient seed is present. On hot, dry, and steep south- and west-facing slopes, shelterwood or very small clearcuts (group selections) offer a better chance for regeneration by leaving a greater seed source and better protection for the site. Clearcuts without seedbed preparation, regardless of the aspect, restock slowly.

4.2.2 Other Natural Perturbations

Other than fire, major natural perturbations to coniferous forests include earthquakes, land and snow slides and flooding. The severity of the damage depends upon the intensity of the initial disturbance and the location of the affected forest; prospects for recovery from these events are subject to the same variables. In some instances, permanent alteration of the landscape will result with attendant changes in the biota of the area.

4.3 MAN-MADE PERTURBATIONS

Probably the most obvious of the man-made perturbations to the coniferous forest of the United States are logging and land clearing for agricultural purposes, construction, and mining. Only in the cases of logging and, recently, strip mining is reforestation contemplated after the clearing or clearcutting of the land. Clearcutting for the purpose of harvesting usually does not entail the processes of stumping, grubbing, and soil importation that would probably occur in the case of a cleanup operation. Clearing for agriculture is generally intended to be a permanent treatment. Therefore, neither of these examples is strictly analogous to the sequence of events that might be involved in the cleanup process. In some respects, the restoration of a forest after a strip mining operation would resemble the cleanup operation, but there is little historic precedence of sufficient age for this to provide prognostic information.

4.3.1 Clearcutting

In addition to the loss of vegetation and disruption of animal habitats, clearcutting has a number of additional effects. The ecological balance of the forest flora and fauna is affected at all biological levels. For example, the loss of habitats from the destruction of the trees may change the bird population in the clearcut area, which in turn may affect the insect population. The slash remaining after clearcutting will offer new habitats for new species, and there may be increased damage to young trees in the regenerating area from diseases and pests[61]. Water quality in a forested area is generally decreased after clearcutting due to increased sediment in the water[52]. Hibbert[30] has reviewed the historical effects of forest treatment on water yield. Generally, he found that removal of forest increases water yield, but he notes that the results of individual treatments were highly variable and were, for the most part, unpredictable. Hibbert also found evidence that the increase in streamflow was proportional to the amount of reduction of the forest. Surface runoff and streamflow were also shown to be increased in the Hubbard Brook experiment. (See discussion by Horwitz[33].) Soil erosion is greatly increased in clearcut mountainous areas. Disruption of the soil and increased insolation alter the microbiological populations after clearcutting. Soil nutrients are leached from the soil in clearcut areas[9].

4.3.2 Strip Mining

Strip mining operations in forested areas represent a widespread source of severe perturbation. Only in recent years have there been significant attempts at reclamation of mined areas, and the technology for doing so is still in a developmental stage. May and Striffler[48] have addressed the watershed aspects of stabilization and restoration of strip mined lands. They found that erosion and sedimentation from disturbed watersheds are attributable to three main sources: slides from sidecast overburden, haul roads, and the mined area itself. Proper spoil placement to ensure bank stability by drainage control will serve to minimize disturbance. Studies of replanting of strip mined areas may be found in Boyce and Neebe[10] and Sindelar, Atkinson, Majarus and Proctor[64]. Many of the efforts at replanting of strip mined lands have not attempted to reproduce the original forest, but rather to stabilize the land with rapidly growing (often imported) species.

4.3.3 Controlled Burning

Fire has been used as a tool in the forest for centuries. In is commonly used now in forest management as a means of decreasing fire potential, for removal of debris after logging operations, etc. Stark[67] has studied the effects of controlled burning of forest understory material upon soil nutrient content. Steele[68] has examined various aspects of smoke management from such fires in relation to atmospheric conditions. A discussion of the environmental aspects of prescribed burning may be found in Fillmore et al.[20].

In the consideration of methods for reforestation after cleanup procedures, assisting recovery through the planting of seedlings seems essential. Tinus[74] has noted that in order to survive, the species and seed source used must be adapted to the particular site, the seedlings must be in the proper physiological state to meet the new environment, and root contact with the soil must be quickly established. When compared with outdoor grown bare root seedlings, containerized seedlings can be more precisely controlled and will not lose root contact with the soil in the planting process. It may also be of interest to consider mychorrhizal inoculation of the soil in conjunction with replanting, if the soil is imported and alien to the forest which is destroyed in cleanup procedures. Mychorrhizal inoculation in afforestation has been reviewed by Milola[49].

4.4 EFFECTS OF CLEANUP PROCEDURES ON CONIFEROUS FORESTS

This section will discuss the effect on coniferous forest ecosystems of a number of possible cleanup procedures.

(0-1) Natural Rehabilitation

The coniferous forest is not always pure but frequently occurs in mixed stands with varying proportions of hardwood pioneers which become established mostly on small bare patches, brush patches, or other non-grassy patches in the disturbed area. An example of primary succession following complete destruction of a conifer forest is that of the six stages of a red spruce forest on mineral soil[75]. The successional stages are:

1. Moss meadow
2. Aster-fireweed meadow
3. Hair grass-sedge meadow
4. Wetlow-birch thicket
5. Aspen forest
6. Spruce forest.

In the north, gray and paper birch, pin and black cherry, and big tooth and trembling aspen are the typical hardwood pioneers. In the south, sweet gum, red maple, and many other hardwoods become established following clearcutting.

Along the east slope of the Rockies, severely disturbed areas, such as those resulting from fires, tend to be colonized first with lichens, moss, and fireweed. Lodgepole pine reseeds concurrently, either in pure pine stands or in association with Englemann spruce in clearings at the upper edge of the coniferous forest. However, cleared areas may be characterized by such harsh climatic conditions near the ground that conifers cannot reseed in the area. Many mountain meadows of the western American ranges may have originated in this manner.

If natural rehabilitation is to be relied upon for the clearcut areas, the major source of seed will be the surrounding forest. Areas with dimensions greater than five tree heights (of the surrounding forest) will not receive adequate coverage. If the treatment is carried out on a fire species such as lodgepole pine or Jack pine, cones will not open and reseeding may not occur.

Although the site may be replanted with coniferous species, hardwoods may soon invade, and subsequent possibilities for variations in the pattern of succession of various sites then become too numerous for generalizations.

(1-1) Chemical Stabilization

Appendix A lists the characteristics of 23 "chemical" and "chemical with mechanical characteristics" stabilizers which are preferred for coniferous forests. These soil sealers and stabilizers mainly include cementitious calcium compounds and mixtures, organic bituminous products, waterproofing agents, and emulsified binders.

The use of emulsifiers is a temporary treatment for stabilizing a soil until vegetation is established. Its effective life is not much beyond 2 years. It would only be useful on sloping areas. It could, to some extent on most treated sites, enhance succession and the development of wildlife habitat by retarding erosion until plants became established. It would not adversely affect any site over and above the primary treatment.

Deflocculants such as salt, sodium hydroxide, and commercial materials such as Calgon, when present on the soil exchange complex in sufficient quantity can virtually render certain soils impervious to water. The degree to which this can be accomplished depends upon soil texture, structure, and the type and concentrations of ions already present in the soil. However, it is assumed the soils of the treated areas would be appreciably affected by the chemical treatment. Accordingly, infiltration would be reduced, and surface runoff increased. Thus, less water would be available for vegetation that might invade or be planted on the site. Erosion on-site and sedimentation off-site would be increased as a result of both increased runoff and the deflocculated soil which would go into suspension more readily.

(1-2) Clearcutting Vegetation

Clearcutting of coniferous forest has been suggested as a possible technique for cleanup of spilled hazardous materials. Precedent for this procedure and many associated problems may be found in the commercial harvesting of Douglas fir in the Pacific Northwest, western white pine in northern Idaho, Jack pine in the Lake States, loblolly pine in the south, and lodgepole pine in the Rocky Mountains. Revegetation in these cases may be achieved through growth of previously established seedlings, natural seeding prior to cutting, artificial seeding after cutting and plant programs. However, it is assumed that in the case of clearcutting for purposes of spill cleanup, the clearcut areas will be replanted or reseeded.

Technically, artificial rehabilitation is applicable to any kind of forest. It contrasts sharply with the seemingly closely related method of clearcutting combined with rehabilitation by natural means which has much greater limitations and gives satisfactory results only under favorable conditions.

Some of the general effects of clearcutting can be summarized[19] as follows:

1. Clearcutting eliminates the danger of wind damage or disease infection to residual trees in the cutover area, but increases the risk of windthrow or heat damage to trees bordering on the cutover area.
2. Clearcutting improves forage for game animals such as deer, elk, and provides habitats for certain animals that were not present before logging. However, streams may be adversely affected by clearcutting with increased temperatures, debris jams, and sedimentation, all of which are detrimental to fish populations. The procedure will also reduce habitats of some of the smaller animals such as woodpeckers, and tree squirrels.
3. Water yields during low-flow periods will be increased by clearcutting; snow catch may also be increased. In swampy areas, the water table may be elevated by the procedure.
4. Clearcutting will permit the use of genetically improved tree planting stock, but growing conditions will be also enhanced for many unwanted brush species, which will compete with the young conifer seedlings.
5. Good growing conditions for shade-intolerant tree species such as Douglas fir and noble fir will be created by clearcutting but seedlings will be exposed to injury from climatic extremes.

Effects of Clearcutting on Climate and Hydrology—Small clearings within forest stands can create extreme effects on the microclimate, and larger clearings significantly affect hydrological factors. As an illustration of these effects, Table 4-1 was taken from Geiger:[25]

Table 4-1. Measurements on forest clearings.

Measurement item	Diameter D (meters)						
	0	12	22	24	38	47	87
Size index D:H*	0	0.46	0.85	0.93	1.47	1.82	3.36
Outgoing radiation (percent of open land)	0	11	31	33	52	66	87
Rain (percent of open land)	-	87	-	-	105	-	102
Temperature (excess over open land midday July)	0	0.7	2.0	2.0	5.2	5.4	4.1

*D = diameter of the clearing, H = height of forest trees, and tree height averages approximately 20 meters.

(a) Temperature: Temperature excesses (temperature increases over those found in the forest surrounding the clearcut) increase with the size of cleared openings in the forest up to a size index of about 1.8 because of solar heating. However, beyond this size temperature again decreases because of wind action. It has been found that size indices less than 1.25 can provide complete frost protection while frost damage will be considerable at indices of 1.50 or greater. In colder regions, air temperatures decrease linearly to about 5°C below the temperature obtained in a closed stand as the diameter of the clearing increases from 0 tc 80 meters. Extrapolation of the data in Table 4-1 indicates that the excesses would be minimal (except for the differences in cooling by transpiration) in clearings 180 meters in diameter.

Soil temperatures within clearings will increase by 2°C to 3°C over those temperatures found in soil beneath a closed stand. In colder climates, spring snow thaws in clearings may occur as much as 4 weeks earlier than in closed stands.

(b) Radiation: Incidented radiation will, or course, be greater in clearings. Albedos will be higher in the clearings and net radiation in clearings may vary between 70 and 90 percent of that in the forest stand.[5]

(c) Soil Moisture: In general, the forest bordering a clearing will deplete soil moisture in the clearing to the extent of their root systems during the summer, while soil moisture within the clearing beyond the forest root zone will remain high throughout the year.[76] Soil moisture within the clearings in mixed conifer forests can be expected to be 5 to 40 percent above that of the surrounding forest.[1, 31, 34, 57]

(d) Precipitation: Although small clearings will, because of wind eddys, tend to increase in rainfall, their greatest effect is upon snow catch. During periods of snowfall in small clearings, incoming snow at one time or another comes from all directions. The ultimate pattern of snow accumulation, however, will most strongly reflect the average velocity and direction of air flow. The zone of maximum snow accumulation will generally be near the center of the clearing.[24,29] Snow catch in small clearings within coniferous forests can be expected to be 20 to 40 percent higher than that found within the forest.[24,54] It should also be pointed out that the total quantity of snow in the forest area will not be increased. Clearings will have the effect of reducing snow catch downwind in the forest.[24]

(e) Runoff: Numerous experiments have demonstrated that clearing a coniferous forest will increase runoff[30] because of reduced transpiration and interception. The amount of additional runoff will vary with the climate of the area, the forest type, soils, slope and aspect. The increase will be greatest during the first year or two after cutting. As the area is invaded by herbaceous vegetation and broad leaf species or as planted stock develops, the effects of clearcutting will decrease (see Section 4.5).

Erosion and sedimentation will not be greatly affected if the forest floor is not severely disturbed by the clearcutting process.

Effects of Clearcutting upon Wildlife—The impacts of clearcutting upon the existing and potential wildlife habitats wihtin coniferous forests may be categorized as: direct alterations to the habitat including obvious damage to the structural and functional aspects of the area; and indirect alterations and changes within the habitat and its surrounding area through interferences with the processes normally provided within the larger natural biological system of the forest. While the true quantitative and qualitative impacts on wildlife generated by clearcutting in terms of ecological recovery and stabilization are subject to debate, some generalizations may be made.

1. The structural alterations resulting from clearcutting obviously influence the mature trees. In the moist cool transcontinental coniferous forest biome between the 45th and 57th latitudes (north), the coniferous forests modify and temper the environment such that the lesser plant species and codominant species are dependent upon them. The removal of the dominant species is equivalent to forcing plant succession back to a more primitive state near the pioneer or early second stage of succession.
2. Habitats are defined by the plant community both structurally and functionally; direct utilization of the three-dimensional space formerly occupied by the clearcut forest for reproduction, food and shelter is no longer possible.
3. The ground plane, depending upon its condition after treatment will redevelop a plant cover of some type. Erosion, drying and heating, and general physical exposure will make this a harsh environment for rapid development.
4. Plant succession will in most cases start anew unless the area is planted. Migration of animal and plant species from adjacent areas will participate in setting the character of redevelopment. If the image and statistical character of this area is to be similar to its surroundings, it must be supported by management activities that recognize the needs of the area in terms of specific habitat requirements.
5. Reutilization of the area by the native mammal, bird, reptile, and insect populations is a function of how well and how fast the former habitat begins to simulate the

the functions of the surrounding area for the support of wildlife, and of the relative adaptability of those species that are able to find niches within the treated area.

The reestablishment of plant stages represents a new-found supply of food and shelter for the wildlife. Competition and simultaneous resource use will prevent this space from developing immediately into its former character.

To bring treated areas back to their former wildlife habitat requires judicious replanting and management. How well and how much these practices are employed will greatly influence the degree and amount of recovery.

(1-3) Stumping and Grubbing

The removal of stumps and roots creates depressions and scarifies the treatment area. The net effect of this treatment would be modification of the effects of simple clearcutting in several ways:

1. Surface runoff would either remain unchanged or possibly be decreased. The additional water storage in depressions created by the treatment would tend to offset the additional runoff that would be caused by antecedent soil moisture.
2. The surface runoff would carry greater sediment loads because of the additional scarification caused in the cutting process.
3. The depressions and scars produced by the treatment would occur at a slower rate after use of clearcutting as a treatment procedure followed by stumping and grubbing, than in the case of simple clearcutting for harvesting due to the absence of roots and stumps for coppice stumping.
5. Small mammal burrows would be destroyed and/or damaged.

(1-4) Scraping and Grading

Scraping of coniferous forest areas would require prior clearcutting and removal of stumps from the treatment area. The litter layer and organic soil layers would be removed in the process of scraping. Accordingly, infiltration rates would be greatly reduced, surface runoff would increase, and detention and retention storage of water would be reduced, resulting in unchecked soil erosion. Further, the residual seed pool in the soil would be greatly diminished and nutrient levels drastically lowered. Depletion of populations of soil-building microfauna and flora would also take place.

Grading of coniferous forest would result in an amplification of all of the effects of scraping treatment; erosion in particular would be increased since smooth grading would eliminate detention and retention storage. The grading equipment would also tend to compact the soil, thereby increasing runoff. Runoff efficiencies, even on slopes as low as 2 percent, might be expected to exceed 60 to 70 percent.[13]

(1-5) Shallow Plowing

This treatment would in most instances require some smoothing of the site following stumping and grubbing. Over the long term, the effects of shallow plowing would probably not differ greatly from simple clearcutting. Over the short term, this treatment would be superior to stumping and grubbing. Essentially, on areas with soils stone-free enough for plowing, and of adequate depth, the area would be tilled as an agricultural field. Surface organic matter would be incorporated into the soil, and the soil loosened, thus creating a good seed bed, and favorable conditions for root development.

The infiltration potential would be increased by the loosened soil resulting from shallow plowing and be enhanced by the creation of a uniform depression storage for water. Assuming that the area will be quickly revegetated, the potential for surface runoff and erosion would be minimized. Such areas would not be unlike abandoned fields. The overall effects upon infiltration created by the shallow plowing would be greater than those resulting from simple clearcutting but not excessively so.

On steep shallow soils which are underlain by shallow bedrock the plowing treatment could create a potential hazard for land slips and slides. By retaining water and with no vegetation to remove the excess water, the soil could become saturated and slip. This would probably be true of soils with low shearing indices, such as those developed from shale materials.

(1-6) Deep Plowing

It is assumed that this treatment would be accomplished either with rippers, root plows or counter-disk plows, all of which can cultivate to a depth of 12 to 18 inches. The deepest depth would be no greater than 24 inches, unless specialized equipment were used. Generally, plowing will have similar effects to those produced by shallow plowing. The treatment would of necessity be restricted to the deeper soils. Infiltration would be improved over shallow plowing, and a greater kill of herbaceous species would be achieved. The natural succession from coppice sprouting and residual seeds in the soil would be delayed for longer periods than in the case of simple clearcutting. The hazard of slips and slides would be increased in mountainous areas. Small animal habitat, burrows, runs, etc., would be largely destroyed.

Plow pans are common on old oil field soils. They hinder deep infiltration, increase interflow[73] and impair root development. Fragipans and hardpans on these often previously eroded soils are also at shallow depths. Deep plowing would break the pans if present. In addition, for those soils where nutrients have leached to lower levels, deep plowing would implement turnover and mixing of the soil. Growth and development of invading species or planted species would be enhanced.

(1-7) Soil Cover less than 25 cm

Soil fill to even these shallow depths would require large quantities of soil material and the use of heavy equipment for hauling and spreading. The forest floor would be buried, effectively smothering much of the life that it fosters and the biological/physical interactions that occur in and near the surface of coniferous forest soils. Small animal populations would suffer loss of habitat and the food supply found upon the forest floor.

Surface runoff will increase and subsequent erosion of the loose dressing material would be severe. On steeply sloping land, off-site sedimentation rates would be high. The effects of the treatment would be comparable to the construction of logging roads[14,23,35] but more severe since larger expanses of area would be involved, and there would be no provisions for compaction and drainage as in the case of road construction.

The low growing plants of the forest floor would be buried and killed. The roots of the taller, herbaceous plants would also be buried and the less hardy of these should be expected to die due to lack of soil aeration.

Since the soil-covering material must be imported, it is likely that it will not have come from a coniferous forest, and that it will probably be a mixture of topsoil and subsoil, or be alluvial material and, as such, it is likely that it will contain low levels of nutrients. In any event, the material will be inferior to the native soil underneath. It will be loose and could provide a good physical seed bed for germination and establishment. The residual seed pool and nutrient level will be low. There is also the possibility of importing plant and animal species with the material that would compete with the natural species. The quality of the imported soil material would be the primary factor affecting early recovery by natural means. If the area is artificially rehabilitated, there should be no appreciable delay beyond that induced by simple clearcutting, unless the covering material is of very poor quality.

(1-8) Soil Cover 25 to 100 cm

The use of deep soil burial would as a treatment tend to magnify the effects mentioned under shallow soil burial. In addition, nearly all of the lower growing herbaceous species would be killed, and the root systems of larger broad leaf species would be effectively buried and smothered. This soil material would contain lower proportions of seeds and organic matter. The potentials for erosion on-site and sedimentation off-site would be increased because of the greater volume of loose material.

The destructive effect on small animal habitats would be complete. Development of herbaceous and broad leaf species would be delayed, particularly on the larger treated areas; this would affect both large and small animals for an extended period.

(2-1) Remove Plow Layer

Logically, removal of the "plow layer" (uppermost 10 cm of soil) would follow stumping and grubbing. In old forest soils this would remove humus layers and most or all of the A horizon. Many coniferous stands, particularly in the East and Midwest, are fire or old field subclimax forests. Loblolly, shortleaf and slash pine exist in the South as the result of fire or previous clearing and cultivation as do Jack pine in the Midwest and lodgepole pine in the West. The forests of white pine in the Northeast and Virginia pine in the Southeast are classic examples of old field subclimaxes which developed on soils with only B or C horizons remaining. Removal of an additional six inches would, except in soils with deep C horizons such as those found in the eastern and southern coastal plains, essentially "sterilize" the areas for long periods. This would be particularly true of coniferous forests located on their characteristically shallow and/or rocky soils in areas of steep terrain. Surface runoff and consequential erosion would be accelerated. The reestablishment of the forest, either naturally or by planting, would be impaired and in some cases impossible.

The effects of this treatment would be less drastic on deep soils. The deeper layers of many coniferous forest soils have a higher nutrient content than the surface material. If the forest is artificially rehabilitated on these treated areas, production should not be greatly impaired.

(2-2) Remove Shallow Root Zone

It is assumed that the depth of this zone is somewhat greater than that of the plow layer. Essentially, the effects of the removal of the described plow layer above would be applicable to removal of the Shallow Root Zone. Both treatments would not leave suitable seed beds for natural rehabilitation and would delay natural succession.

(2-3) Remove Scraping and Grading, Mechanically Stabilize

The effects of scraping and grading have been described in treatment 1-4 above. Mechanical treatment in addition to the scraping and grading is assumed to involve compacting of the area with mechanical equipment (e.g., rollers, vibrators, rams, etc.). Thus, it would first be necessary to clearcut the trees, remove slash, stump and grub roots, and smooth the area.

The smoothing treatments could involve grading, scraping, soil removal and burial with imported soil. In any case, the degree of compaction will be affected more by the nature of the soil material, the soil moisture content, and the compaction treatment than by the particular smoothing treatment. Therefore, it is assumed that those areas to be mechanically treated will essentially exhibit similar enviornmental effects and recovery rates, regardless of the smoothing treatment used.

The average depths of compaction by various types of machines are given in Table 4-2. The actual depth for a specific site will vary with soil characteristics. Generally, at optimum moisture contents, compaction potential will increase in the order: heavy clay, silty clay, sandy clay, sand, and gravel-sand-clay.

Table 4-2. Average possible depth of compaction to 10 percent soil voids (from Armstrong[4]).

Equipment	Depth Compacted (in.)
2 3/4-ton smooth-wheel roller	5
8-ton smooth-wheel roller	6
2 1/2-ton vibrating roller	5
2-ton vibrating plate compactor	12
D-8 crawler tractor	6
Ram (portable)	6

Footed rollers, either sheeps foot or taper foot, comprise a special class of compactor for cohesive soils. At least 64 passes are required to completely cover a given area. Depth of compaction can reach 18 inches or more.

The effects on microclimate of mechanical treatment will not differ from those of clearcut areas. Wildlife should find little interest in the treated areas since it will not support appreciable amounts of vegetation for several years.

(2-4) Remove Plow Layer, Mechanically Stabilize

The effects of this treatment are essentially the same as those described in treatment 2-3 above.

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

The effects of this treatment are essentially the same as those described in treatment 2-3 above.

(2-6) Remove Scraping and Grading, Chemically Stabilize

The result of the addition of a chemical stabilizer to stumped and grubbed land which has been smoothed would depend on the type of chemical treatment. Chemical emulsifiers will counteract the effects of scraping and grading by stabilizing the soil bed until vegetation is established. They could speed succession by retarding erosion until plants became established. Chemical deflocculants will intensify the effects of the mechanical disturbance. They will reduce infiltration and increase surface runoff. Less water will be available for vegetation that might invade the site, thus succession will be retarded.

(2-7) Remove Plow Layer, Chemically Stabilize

The effects of this treatment are essentially the same as those described in treatment 2-6 above.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

The effects of this treatment are essentially the same as those described in treatment 2-6 above.

(3-1) Barriers to Exclude People

The exclusion of humans would have no negative effects on the natural processes within the exclosure, and could be beneficial, especially in areas of high population density.

(3-2) Exlude Large Animals

Barriers that exclude large browsers, grazers, and predators will affect the succession within the exclosure. With the exclusion of browsing and grazing animals, a greater density and diversity of herbaceous species will develop whether or not the coniferous forest cover is removed. If the trees are removed, the early stages of succession will be extended and the development of the climax forest will be prolonged.

The presence of more herbaceous plant species results in making available more energy to the small herbivores. In addition, herbivore population should increase due to the absence of some of their predators. Small predators not limited by the exclosure (slumber weasel, etc.) will increase due to the additional food supply and absence of competitive predators.

The elimination of the soil compaction produced by the larger mammals may favor the rehabilitation of the forest floor and the reestablishment of its ecological processes.

The large biota mammal habitat would be minimally influenced by small exclosures. Large exclosures (10 km^2) in areas of limited forest could have serious negative impacts upon the local area. Home ranges of the larger animals (deer, elk, bear, cougar, etc.) are invariably larger than the largest treated areas proposed. In the densely populated forest areas of the eastern United States, and to a lesser extent in the more sparsely populated western states, large exclosures could interfere with animal movement.

Barriers that exclude large browsers, grazers, and large predators will ultimately influence the dynamics of succession within the exclosure. An immediate reduction in browsing and grazing will favor the development of plant species subject to these processes. These plant species, which usually include the grasses, forbes, shrubs and palatable tree seedlings, will experience a measurable increase in growth, an increased density and therefore higher measurable productivity (accumulated biomass). These (r-strategy)* plant species tend to dominate the earlier stages of plant succession when moisture, available nutrients and light quality are favorable. Their removal favors those less palatable tree species (k-strategy) typical of later successional stages. Therefore browsing and grazing can foreshorten plant succession and create conditions which favor faster rates of development toward climax.

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*Using the terminology of growth equations where r is the intrinsic rate of increase, and k is the upper asymptote or equilibrium population size. r selection predominates in early colonization with k-selection prevailing as more and more species and individuals attempt to colonize.[50]

If trees are removed, the early stages of succession will be extended, ultimately prolonging the development of a climax forest.

(3-3) Exclude Large and Small Animals

This treatment would benefit birds and tree-dwelling animals because of the resultant additional availability of protection and food. The effects on the density and diversity of herbaceous vegetation within the enclosure and the subsequent effects on microclimate, soil compaction and succession would be amplified over those resulting from the exclusion of large animals.

It is also expected that any small animals trapped within the exclosure would benefit, particularly if a source of water were available. Gene flow would be restricted, but this effect would not be significant unless the exclosure remained effective for many reproductive cycles.

(4-1) Asphalt Hard Surface Stabilization

Paving a contaminated area represents a severe impact. Asphalt may be laid either between the trees or after trees have been removed and the site smoothed. Asphalt laid between the trees will result in the gradual (1 to 3 years) death of the trees in the treated area. Coniferous trees have relatively shallow roots and depend on the infiltration of surface water for moisture and nutrients. Paving the surface will block infiltration, and runoff efficiency will be 90 to 98 percent of the rainfall. Plant or animal invasion of the area would be delayed until the asphalt begins to decompose. The existence of decaying trees on the site would speed the process of asphalt breakup by mechanically disturbing the surface as the trees fell.

(4-2) Concrete Hard Surface Stabilization

The effects of this treatment are very severe and are essentially the same as described in treatment 4-1 above. Infiltration of surface water would be stopped. Runoff would be virtually 100 percent of rainfall leading to extensive off-site erosion. Establishment of a community would require complete breakup of the concrete, a process that would required decades to centuries.

(5-0) Application of Sewage Sludge

Sewage Sludge Application Without Clearcutting—The effects upon coniferous forests and their associated wildlife of applying sewage sludge to the forest soils are dependent upon the characteristics of individual wastewaters. Chemical contaminants in wastewater may be classified as either inorganic (heavy metals) or organic including PCBs, pesticides and other synthetic materials. Pathogenic biological pollutants include a wide variety of bacterial, protozoan, parasitic helminth and viral forms. Wastewater treatment processes can provide significant reductions in the levels of these contaminants, but conventional treatment processes are not adequate to remove certain chemical and biological pollutants.

In general, based upon studies in Douglas fir stands[17,55,69] the application of sewage sludge may be predicted to have the following effects:

1. An increase in the rate of forest floor decomposition
2. An increase in the rate of tree and ground cover growth
3. A possible initial decrease in surface water infiltration in the short run due to the presence of fine sediment in the sludge, but a net long-term effect of increased infiltration due to enhanced ground cover growth
4. A decrease in anaerobiosis in the upper soil profile
5. An increase in coliform bacteria which will move through the soil profile with the soil solution
6. An increase in the flow of nitrates through the soil system accompanied by the stripping of cations from the soil complex
7. An increase in carbon dioxide production resulting from organic decomposition processes in the soil
8. An increase in cationic losses due to increased mobile anion pools
9. An increase in heavy metals in soils and animal tissues (see also Peterson et al.[53])
10. An increase in microbial aerosols, depending upon the method of application of the sewage sludge.

Phosphorus may also increase, particularly in those soils having high exchange capacities; however, it is most likely that such accumulation will occur primarily in the upper soil layers.[27,78] Soluble salts of soil extracts, notably chlorides, sulfates and calcium, will also be increased.[32] In general, animal viruses have not been detected following sewage sludge application.[43,69]

Accumulation of heavy metals in plants grown on sludge-amended soil has been found to be greater than that found in plants grown on untreated soil, although toxic levels have not been detected.[56] Similarly, dangerous levels of heavy metals in the tissues of birds and small herbivorous mammals sampled in sludge-amended areas have not been detected.[3,18,21]

It may also be expected that populations of larger browsing mammals would increase due to the availability of additional forage. The effects of sewage sludge application upon invertebrates will vary from species to species. Earthworms and other invertebrates will probably tend to increase due to the higher nutrient levels provided by the applied effluent. If the area is heavily irrigated, the diversity and numbers of most soil microarthropods will decrease.[16] Song birds may increase because of greater food availability.[3]

Sewage Sludge Application Combined With Clearcutting — The combined effects of clearcutting and sewage sludge application on soils will be similar to those produced by sludge treatment alone. In addition, the growth of ground cover, particularly that of broad leaf species will increase. Accordingly, the return to a coniferous forest will be delayed or possibly prevented entirely unless the area is artificially rehabilitated. The effects on wildlife will be essentially those discussed in the clearcutting treatment 1-2 above, but with the additional enhancement of food supply.

4.5 RECOVERY AFTER CLEANUP

4.5.1 Irreversible Changes

Over the very long run (thousands of years) the consequences of all of the treatments discussed here are theoretically reversible, assuming that no major climatic changes occur and that the requisite sequence of events and conditions obtain for the successional reestablishment of the original coniferous forest. Over a period of a hundred years or less, hard surface stabilization, particularly in the case of concrete treatment, may be considered as virtually irreversible. Other treatments such as removal of the plow layer, if done on a shallow soil on a steep hillside, might also be irreversible if no supplemental remedial treatments are applied.

4.5.2 Rates of Recovery

The perturbations discussed in this chapter on cleanup procedures do not have a great deal of precedence. The only common analogous situations are clearcutting, fire, surface mining, and abandoned fields. Even under these situations natural successions will not necessarily lead to the same subclimax or climax coniferous forest that existed prior to the disturbance. For example, Douglas fir in the west seldom reestablishes itself naturally following clearcutting. Longleaf pine, an important species in the south, does not always reseed itself on burned areas. Loblolly pine, an old field species, may not become reestablished on adjacent old fields that are first invaded by hardwood species and then protected from fire.

If it is desirable to have the treated area return to its former productivity as soon as possible, then artificial planting is the restorative method of choice. Seedlings of nearly all of the important conifer species are grown in State or Federal nurseries. The largest treatment area considered, 10 km^2, would require only about 250,000 seedlings, well within the production capabilities of any large nursery. In northwestern Mississippi, a planting schedule of 50,000,000 loblolly pines annually was maintained for many years.

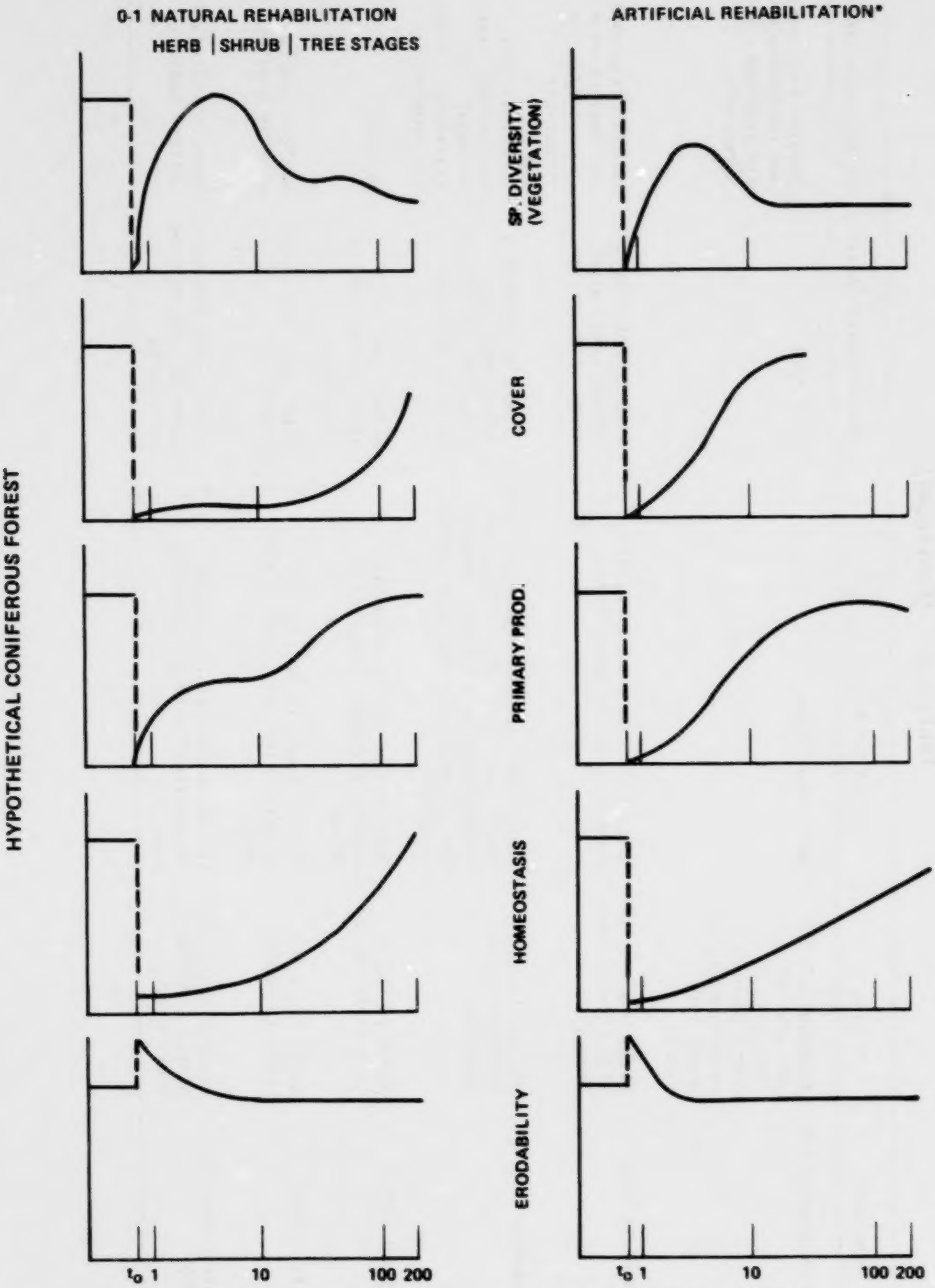
Table 4-3 summarizes the successional associations of some major coniferous forest types. Recovery sequences over future time are shown graphically to demonstrate the duration of treatment effects, assuming no retrogression occurs. The endpoint for the curves in Figures 4-3 through 4-5 is restoration of productivity to the extent that a layman would view it as similar to the productivity of undisturbed areas. Representative cleanup treatments were illustrated in the figures and the application of that information in evaluation of the impact of cleanup on coniferous forest is demonstrated in some detail in Appendix B.

Table 4-3. Major forest types of the United States.

Type Name	Region	Principal Associate Species	Successional Stage	Climax Association
White Pine	Appalachian	Yellow-poplar, chestnut, hemlock, red oak, white oak, scarlet oak	Long-lived, temporary on abandoned lands	Northern hardwoods
Shortleaf pine	Appalachian & Piedmont	White oak, southern red oak, post oak	Climax on certain areas, old-field type on others	Oak-pine-hickory
Virginia pine	Appalachian & Piedmont	Shortleaf pine, chestnut oak, white oak, red oak	Temporary, old-field	Oak-pine-hickory
Loblolly pine-shortleaf pine	South	Persimmon, blackgum, post oak, red oak	Subclimax	Pine-hardwoods
Loblolly pine	South, Coastal Plain	Sweetgum, southern red oak, blackgum, laurel oak	Subclimax	Pine-hardwoods
Longleaf pine-slash pine	South, Coastal Plain	Water oak, laurel oak, post oak, live oak	Subclimax	Pine-hardwoods
Douglas fir (Pacific, 80%; interior, 50%)	Pacific Coast & Rocky Mts. into Canada, & south to Mexico	Most western trees native to locality	Generally fire type except in drier habitats where it becomes climax	Climax only on relatively warm, dry habitats. Western redcedar-western hemlock & spruce fir succeed it on cooler, moister habitats
Englemann spruce-subalpine fir	Rocky Mts. & Cascades into Canada	Most western trees native to locality except "xerophytes" such as ponderosa pine and junipers	Climax, although type may follow directly after logging or fire without intervening stages	Spruce-fir

Table 4-3. (Continued)

Type Name	Region	Principal Associate Species	Successional Stage	Climax Association
Larch-Douglas fir	Washington & Oregon east of Cascades, & north Idaho & western Montana, north into Canada	Most local trees	Fire type	Douglas fir, western hemlock-western redcedar, or spruce-fir
Lodgepole pine	Rocky Mts. to Pacific Coast & into Canada	Most local trees but frequently occurs in nearly pure stands	Fire type but very stable over large areas in Rocky Mts.	Douglas fir, western hemlock-western redcedar, or spruce-fir
Ponderosa pine	Pacific Coast to Black Hills and Nebraska	Nearly pure stands occur over large areas, but on moister sites, most native trees intermingle. Douglas fir and white fir are most common associates	Climax on warmest & driest habitats. Temporary on cooler, moister habitats	Ponderosa pine within that vegetational zone. Elsewhere, generally Douglas fir
Redwood (20%)	Northern Calif. & southern Oregon	Douglas fir, western hemlock, western redcedar, and Port-Orford-cedar	Climax, but will also follow fire or cutting	Redwood
Sitka spruce	North Pacific Coast to Alaska	Western hemlock, Douglas fir, Pacific silver fir, and western redcedar	Fire type, but very stable	Western redcedar-western hemlock
Western Hemlock (80%)	Pacific Coast to Alaska & northern Rocky Mts.	All local species except the "xerophytes" such as ponderosa pine	Climax, but may also directly follow fire or logging	Western redcedar-western hemlock



*Clear Cutting (1-2), Stumping and Grading (1-3), Plowing (1-5, 1-6), Shallow Soil Burial (1-7), Flooding (6-2).

Figure 4-3. Sequence of ecological recovery following cleanup.

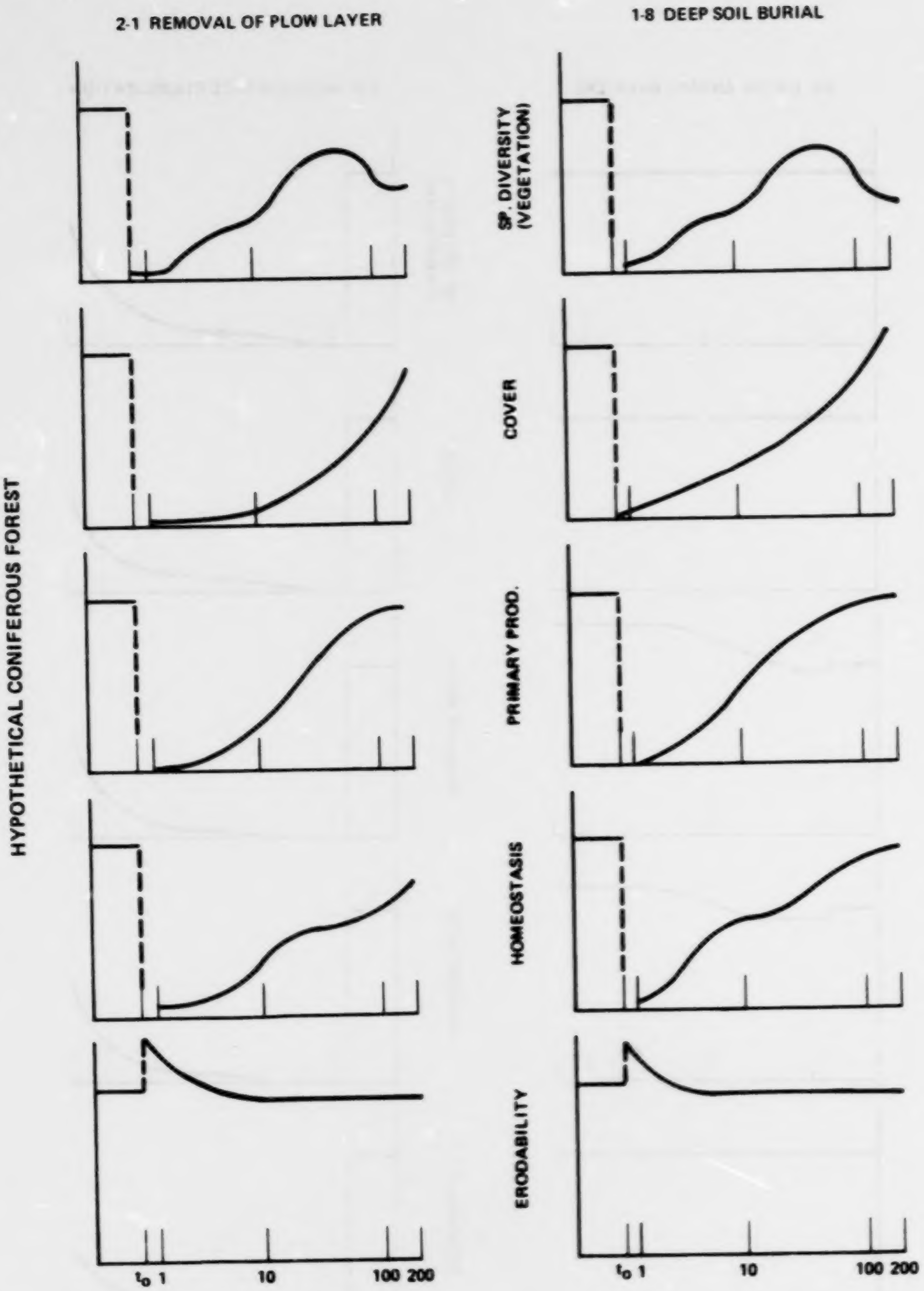


Figure 4-4. Sequence of ecological recovery following cleanup.

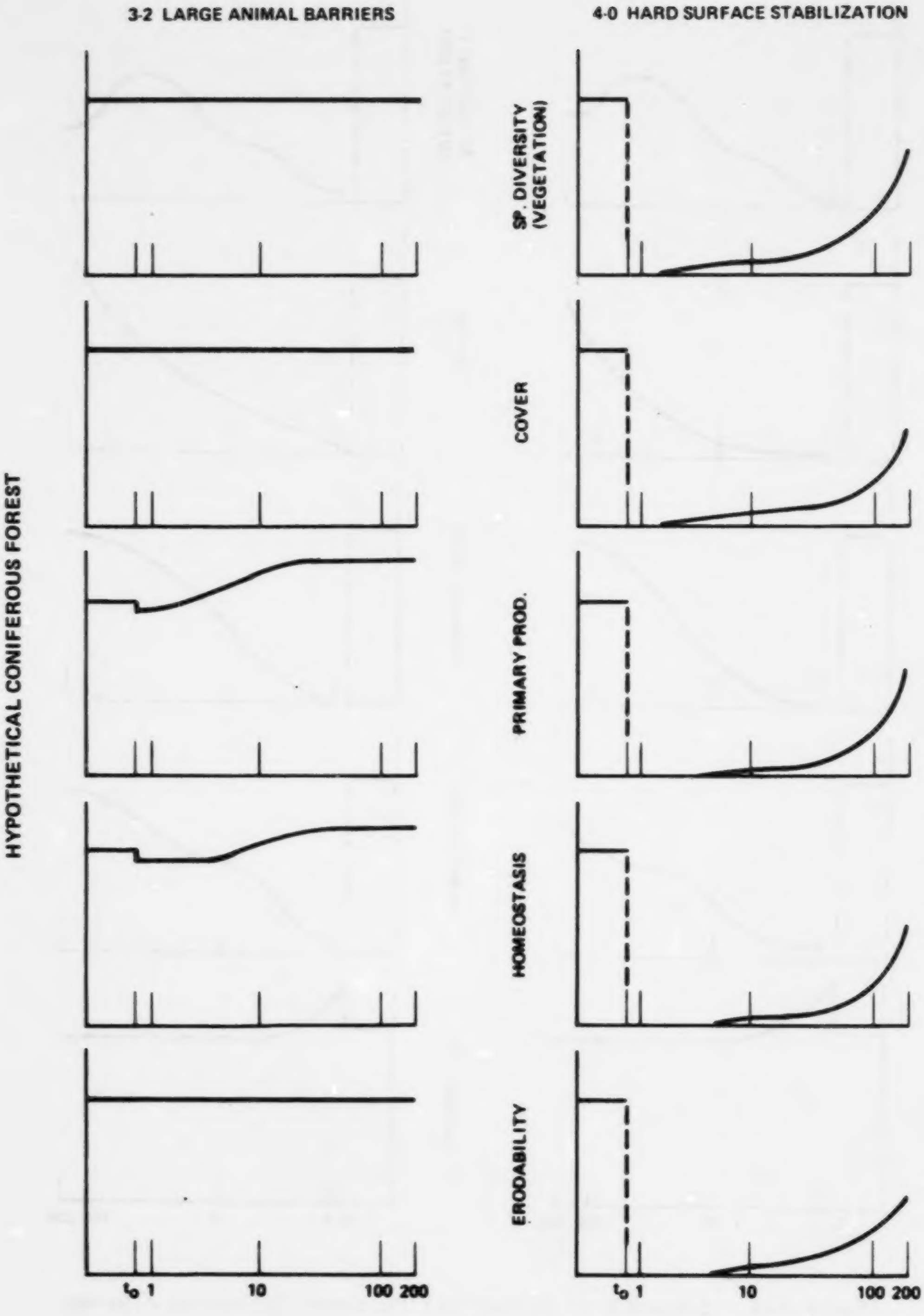


Figure 4-5. Sequence of ecological recovery following cleanup.

4.5.2.1 First Year --

During the first year after a clearcut treatment, the remains of the understory hardwoods would sprout, and the released herbaceous plants and grasses would develop rapidly. Pioneer plants, primarily annuals, would begin to invade the area, and conifer seedlings present on the area would develop.

Natural reseeding from the trees bordering the clearcutting could possibly occur if the treatment was performed during a seed year. Otherwise the area would have to wait, and during this time the competitive understory will have had an opportunity for greater development. If the particular conifer species does not reestablish well (e.g., Douglas fir) or is unable to compete with understory hardwoods (e.g., Virginia pine) it is possible that the stand will retrogress to brush or hardwoods.

If the area were replanted, the original stand density could, for most conifers, be reestablished in the first year, and complete crown cover could be obtained in 5 to 20 years depending upon the species.

The use of the area by animals, mainly transient herbivores, during the first year would tend to increase because of the development of additional ground cover. This would continue to a peak use at the beginning of crown closure of the conifers.

Areas which have been stumped and grubbed and subsequently graded, scraped, plowed, or had topsoil removed, or areas which have been dressed with imported soil material will show less development than the clearcut treatment. Grading, scraping, and topsoil removal will produce the poorest conditions for rehabilitation and the areas will be vegetated primarily with pioneer species during the first year. Stumping and grubbing and plowing treatments will produce good seed bed and moisture conditions and will not be greatly inferior to the clearcut treatment.

Runoff will be increased the first year on the clearcut areas (Figure 4-6). Runoff rates will be highest for topsoil removal, scraping and grading treatments and will carry higher sediment loads from erosion. Runoff may also be higher from areas stumped and grubbed, plowed or covered with

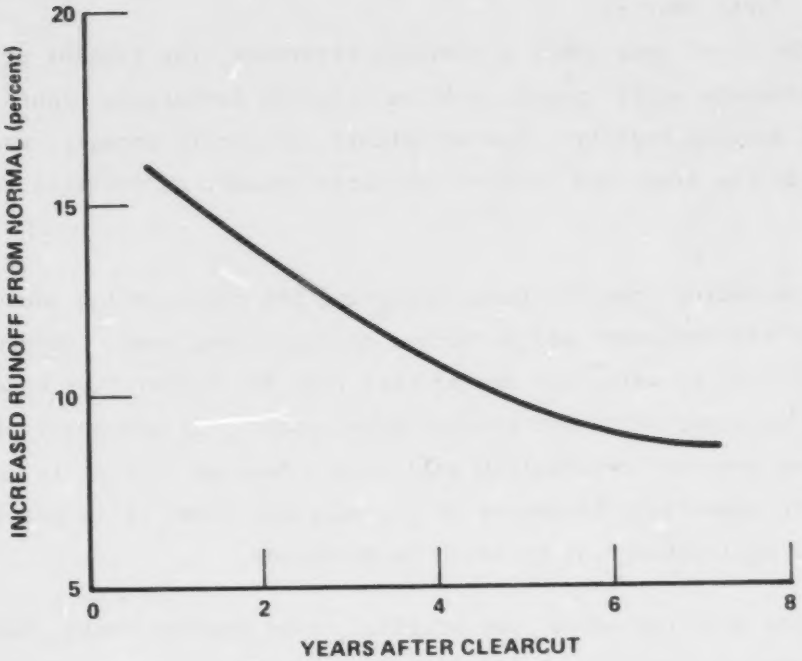


Figure 4-6. Decrease in runoff following clearcutting coniferous forests (after Swane and Mines[72]).

imported soil material, depending upon depression storage and infiltration characteristics, but it will carry heavier sediment loads than expected from the simple clearcut treatment.

The effects of chemical and mechanical stabilizers combined with other treatments would be greatest for the soil removal, soil burial and scraped treatments, and least for the stumping and grubbing and simple clearcut treatment. Recovery of the area would be delayed until leaching occurred and soil structure could re-form. Treatments which left the most organic matter would recover more rapidly, but succession on the site should be expected to be delayed at least 5 years by the treatment.

With the exception of the chemical emulsions, the application of stabilizers will require: (1) breaking up and tilth forming; (2) application and mixing in of the stabilizer; (3) application of water to, or its part removed from, the soil to achieve moisture control; and (4) compaction. Thus, the treated area must first be clearcut, stumped and grubbed, slash removed, smoothed and plowed. The stabilizing treatment would show effects far in excess of those between the additional treatments of topsoil removal and burial with imported soil. It is therefore assumed that all treatments (e.g., stumping and grubbing, grading, smoothing, burial, soil removal and plowing) will have very similar effects and responses after stabilization.

Generally, the effects on wildlife succession and hydrology will be greater than those of simple mechanical stabilization. Succession and wildlife habitat will be retarded for at least an additional 5 to 10 years, and runoff efficiency will increase to above 70 percent. However, erosion and sedimentation will be considerably less than for the mechanical treatments, but structures to handle the excess runoff will have to be installed to minimize offsite damage from runoff.

Complete recovery of a site subjected to a combined treatment, in some cases, may take centuries. Soil with high proportions of montmorillonite clay and soil in areas subject to heavy frosts will loosen within a few years. Soils in the sub-humid areas where rainfall is high and plant invasion occurs at higher rates may require up to 5 years for the establishment of a complete ground cover of pioneer species. It is assumed that the area would not be suitable for planting. Thus, depending upon location, soil characteristics and degree of compaction, succession will be delayed over that which might occur on the simple clearcut area by 25 to 100 years. Of course, heavily compacted areas would be very prone to retrogression.

This tendency would be amplified by the increased surface runoff and erosion that would result from treatment. A compacted area, even if compacted by a sheeps foot roller, and devoid of vegetation and depression storage, will present little friction to flowing water. Infiltration, particularly in soils with clay and silt components, will be reduced at least to 1 inch per hour or less. It is expected that runoff efficiency will be on the order of 70 percent or more.

The damage from offsite runoff, even from areas of 1 hectare, could be considerable and would require the construction of diversions, lined channels, or dams for water storage and desilting.

4.5.2.2 Fifth Year --

Three years after treatment, assuming successful rehabilitation of the conifer, if erosion has not been severe and if the site is of good to medium quality, the forest growing conifer species (e.g., loblolly, short leaf, slash, etc.) will have attained heights of 20 to 60 inches.[11] The slower growing species, such as Douglas fir, will have reached 15 to 20 inches.[70] At ten years, heights of the faster growing species will be on the order of 20 to 30 feet, and those of the slower species will have attained heights of 4 to 5 feet.[28,71] In the moist temperate zones, crowns will have started to close and stratification will have begun. In colder regions, there will still be heavy competition between hardwood brush and coniferous species.

If natural rehabilitation (0-1) were relied upon and had been successful the density of the new reproduction might appear as shown in Figure 4-7, to dense near the seed source and sparse or absent at greater distances.

The plowed areas will probably exhibit the best reproduction followed in order by stumping and grubbing (1-3), simple clearcut (1-2), soil burial (1-7), scraping and grading (1-4), and soil removal (2-1 through 2-8). In stands with associated hardwoods, the effects of sludge treatment may be evident in a greater development of hardwood competition.

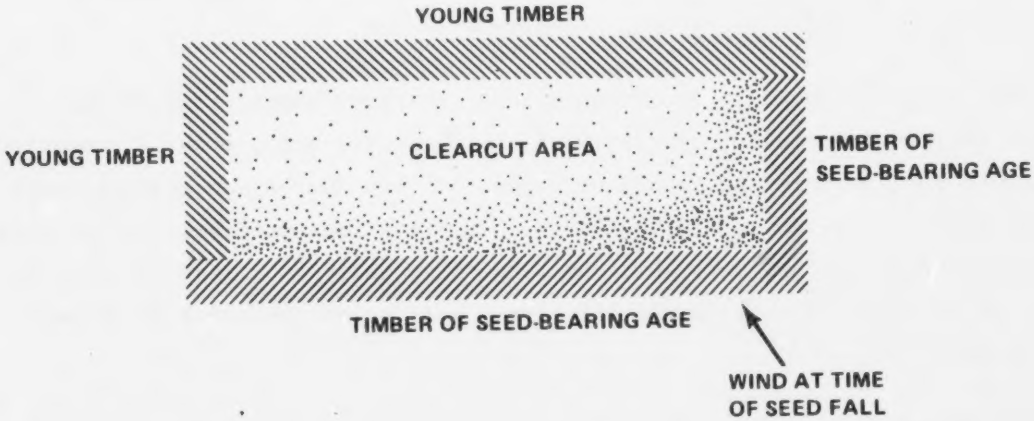

YOUNG TIMBER
YOUNG TIMBER
CLEARCUT AREA
TIMBER OF SEED-BEARING AGE
TIMBER OF SEED-BEARING AGE
WIND AT TIME OF SEED FALL

Figure 4-7. Clearcutting the whole stand, with reproduction secured by seed disseminated from seed trees located outside the cut stand. The density of the reproduction 5 years after the cutting is indicated by the dots (from Smith[66]).

The effects of forest removal on surface runoff will have diminished as indicated in Figure 4-4. Runoff from the concrete and asphalt areas will not be appreciably diminished since these materials will not have deteriorated greatly.

In those forests with associated hardwoods, the crown cover of hardwoods within clearcut areas will have developed in some stands to the point of closure and will provide cover and food for wildlife. Use of the area will be enhanced by the border created by the clearing.

Within the exclosure, competition of hardwood and herbaceous species may have delayed conifer growth.

4.5.2.3 Fiftieth Year --

On clearcut areas (1-2) with or without supplemental treatment (e.g., stumping and grubbing, plowing, etc.) which were successfully restocked, either naturally or artificially, complete crown cover will have been obtained and the herbaceous and hardwood understory will have been suppressed. Stratification of the forest into dominants, codominants, intermediates, and suppressed trees will have developed. The number of trees per unit area, except in the boreal forests, where such processes occur at slower rates, will have decreased due to suppression by larger trees as indicated for representative tree age in conifer forests in Table 4-4.

Table 4-4. Approximate age of representative coniferous forests where number of trees per acre is reduced by suppression.

	Approximate age (years)
Eastern Forests	
White - red Jack pine	20 to 30
Loblolly-shortleaf pine	20 to 25
Spruce-fir	30 to 40
Western Forests	
Douglas fir	30 to 40
Ponderosa pine	20 to 30
Hemlock-sitka spruce	110 to 120

The effects of the clearing treatments on wildlife, runoff and erosion will not be evident. The wildlife habitat will have been essentially stabilized to that of the surrounding forest. It is possible, but not likely, that the exclosures could remain 100 percent effective, even if maintained, over this long a period.

Asphalt treated surfaces (4-1), if not maintained, will appear as do abandoned World War II air strips today, heavily cracked and buckled and invaded by grasses and pioneer species. The concrete treated areas (4-2) will, of course, be weathered but still intact except for plant invasions in cracks or expansion joints. Offsite scouring and gullying by concentrated runoff from the areas will still be active, assuming that any structures installed to prevent this have not been maintained. The areas treated by sludge (5-0) will show no significant effects of treatment by this point in time.

It is not possible to make general predictions for those sites that may have retrogressed as a result of the treatment applied. The effects could range from exposure of bedrock to the development of a permanent meadow, depending upon the particular site and treatment.

4.5.2.4 100 Years After Treatment --

In all cases except the boreal forest, assuming that artificial rehabilitation or successful natural rehabilitation of clearcut areas has occurred, the new coniferous forest will be approaching maturity. The forests of the southeast will have passed the point of commercial maturity. The dominant trees will have attained heights equivalent to the representative data in Table 4-5. Basal area development will be on the order of data presented in Table 4-6.

On areas treated by scraping, grading, topsoil removal and burial, a maximum depth of litter will have accumulated on the forest floor. An F horizon will have begun to develop, but otherwise the rest of the soil profile will show no appreciable development. The soils of the other treatments will show no significant change.

Wildlife habitat 100 years after treatment will not be discernible from the surrounding habitat, assuming that no additional perturbations have occurred

Table 4-5. Height of dominants in a fully stocked stand at 100 years — good to medium site fully stocked.

	Height (feet)
Eastern Forests	
White - red Jack pine	80 to 100
Loblolly-shortleaf pine	80 to 90
Spruce-fir	50 to 60
Western Forest	
Douglas fir	120 to 140
Ponderosa pine	90 to 100
Hemlock-sitka spruce	40 to 120

Table 4-6. Approximate basal area (m^2/ha) of representative conifer species — good to medium site, fully stocked (after Forbes[22]).

Eastern Forests						Western Forests		
Age (yrs)	Loblolly pine	Slash pine	Eastern white pine	Red spruce	Jack pine	Ponderosa pine	Douglas fir	Sitka spruce and western hemlock
20	29	32			29	19	21	25.5
30	35	36	41		32	35	32	43
40	37	37	48	29.5	33	45	40.5	50.5
50	38.5	37.5	53	44	33	48.5	47	56.5
60	39.5	38	55.5	38.5	32.5	49	52	62
70			57.5	49	31.7	49	56	66
80			59	53.5	29	49	59.5	69
90			60.5	57		49	62.5	72
100			61	58.5		49	65	74
110			61.5	59.5			67	76
120			62				69	77.5
130							71	78.5
140							73	80
150							74.5	81

to either the naturally rehabilitated or treated forest areas. However, it is unlikely that the exclosures will have been maintained for this long a period. Thus, evidence of the exclosures and their effects would not be apparent.

There is no precedent for predicting the effects on succession of the concrete and asphalt treatments. It is reasonable that natural succession will have been delayed for at least 50 years by the asphalt treatment and more than 100 years for the concrete treatment. Even after such a long period, the spatial patterns of the process would be controlled by the breakup pattern of the covering.

The succession processes on the clearcut treatments will be approaching maturity. In areas where hardwoods are the climax species, broad leaves will begin to dominate. For other climaxes (Ponderosa pine in Arizona, for example) the area will support a pure (unmixed) mature stand. However, the surrounding stand will have become over-mature and have begun to retrogress.

4.6 QUANTITATIVE ASSESSMENT OF CLEANUP IMPACTS

The relative severity of the different cleanup treatments on various environmental parameters is shown in Figures 4-3 and 4-5 and Appendix B, Table B-3. It is apparent that the most severe cleanup techniques are hard surface stabilization (4-0) and soil removal (2-1 through 2-8), while the least severe treatments are exclusion by barrier (3-1 and 3-2) and application of sludge (5-0). This reflects the unfortunate fact that there is an inverse relationship between a treatment's effectiveness in contaminant demobilization and its destructive environmental impact.

Lawrence[40] has described the hypothetical development of a spruce-hemlock forest following glacial retreat. He estimated that climax could be reached within 130 to 200 years, at a median of 170 years. Other authors agree that the duration of sere from bare mineral soil to climax coniferous forest is about 200 years. Using this generalization, and noting the duration of successional periods in the development of mature forest given by Lawrence,[40] a series of index numbers from zero to nine (not measurable to irreversible) can be imposed on the set of successional periods. These index numbers can then be applied to the cleanup treatments performed over different areas, the index numbers representing the approximate point in the sere to which the cleanup treatment retrogresses the climax forest. The result serves as an indication of the relative severity of the treatments. Table 4-7 presents this analysis for different sizes of disturbed areas and the details are given in Appendix B.

As expected from consideration of Table 4-7, the most severe treatments over all areas are mechanical soil stabilization after soil removal (2-3 to 2-5) and hard surface stabilization (4-0). In consideration of treatments 2-3 through 2-5, it must be realized that erosion of the land after scraping and compaction is a very important factor in the indicated severity of these treatments. With treatment 2-3, the removal of only the upper five centimeters of soil will assure that some roots remain, from which vegetation will emerge to check erosion during the first season after treatment. However, as deeper soil layers are removed through treatments 2-4 and 2-5, little or no rhizomal material will remain to sprout erosion-inhibiting vegetation. Because of the compaction of the soil, seeds blown in from surrounding areas will not find germination sites until rills and gullies have started to form, particularly on sites with greater slope. In almost all conceivable situations, human intervention, in the form of gully control and artificial seeding and planting, will be required to ensure recovery of the coniferous association within half a millenium.

Hard surface stabilization, treatment 4-0, also represents serious destructive impact to the coniferous forest. Asphalt will decompose at rates determined by climate, slope aspect, asphalt composition, and vigor of mechanical pavement destruction by vegetation and frost. However, concrete, due to its inorganic nature and resultant resistance to decomposition, will have consistently higher durability than asphalt in various biomes. If the earth is compacted or any exotic subgrade is used below the concrete, vegetative recovery will be further inhibited to the point where human intervention will be required to ensure recovery of the coniferous association. Small areas of high-level contamination may be served best through this treatment, since it is the most effective and provides the greatest public safety. However, for areas larger than 0.1 km^2, this treatment can be considered unacceptable.

Table 4-7. Recovery index in coniferous forest for various cleanup treatments (see Appendix B).

Treatment	Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	4	4	5	5	No seed reserve, average seed bed
1-1 Chemical Stabilization	2	2	3	3	Seed reserve, average seed bed
1-2 Remove Vegetation by Clear Cutting	2	2	2	2	Seed reserve, good seed bed
1-3 Remove Stumps and Grub Roots	2	2	2	2	Seed reserve, gooc seed bed
1-4 Surface Scraping and Grading (<5 cm)	2	2	2	3	Some seed, poor seed bed, erosion
1-5 Shallow Plowing (<10 cm)	2	2	2	2	Some reserve, good seed bed
1-6 Deep Plowing (10 to 40 cm)	4	4	4	5	No seed, average seed bed, erosion
1-7 Soil Cover (<25 cm)	4	4	4	5	No seed, average seed bed, erosion
1-8 Soil Burial (25 to 100 cm)					
2-1 Remove Plow Layer Soil (10 cm)	4	4	4	6	No seed, poor seed bed, erosion
2-2 Remove Shallow Root Zone Soil (<40 cm)	5	5	6	7	
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	7	7	7	7	No seed reserve, very poor compacted seed bed
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	8	8	8	8	No seed reserve, very poor compacted seed bed
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	8	8	8	8	No seed reserve, very poor compacted seed bed
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	4	4	4	5	No seed reserve, very poot compacted seed bed
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	4	4	4	5	No seed reserve, very poor compacted seed bed
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	4	4	4	5	No seed reserve, very poor compacted seed bed
3-1 Barriers to Exclude People	0	0	0	0	Climax is initial stage
3-2 Barriers to Exclude Large Animals	0	0	0	0	Climax is initial stage
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	Climax is initial stage
4-1 Asphalt Hard-Surface Stabilization	7	7	7	7	
4-2 Concrete Hard-Surface Stabilization	8	8	8	8	At least 50 years required for concrete breakup
5-0 Sewage Sludge Application	0	0	0	0	
6-1 Washing (<3 mm)	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	
7-0 Soil Amendments Added	*	*	*	*	

*Outside scope of work.
Greater impact shown by larger number (see Appendix B)

Other treatments have serious impacts when applied over large areas. Removal of the plow layer (treatment 2-1) or shallow root zone (treatment 2-2) has serious effects over the larger areas. First, because the best soil is removed by the treatment, new topsoil must be formed before most species can return. Second, the effects of erosion will be much more severe over the large areas than over the small areas. That is, over areas of from 10 to 100 km^2 erosion will proceed almost as rapidly as soil formation and vegetation recovery, while over areas of 0.01 to 1 km^2 vegetative recovery will occur much faster than erosion. This is because the turbulent currents which produce accelerated water erosion and the high surface wind velocities which produce accelerated wind erosion rarely occur over small areas, while they are common over large, barren tracts. An exception would be the case of a small area of high slope, where water erosion would be quite severe.

Finally, chemical soil stabilization (treatment 1-1) and soil cover (treatments 1-7 and 1-8) would have serious impacts at the scale of 100 km^2. In the case of chemical stabilization this is because, over such a large area, erosion would probably overwhelm the stabilization effect of the compound, thus pushing vegetative recovery to or beyond the maximum natural recovery span. The importance of erosion over larger areas is also the reason why soil cover is considered a drastic treatment at the scale of 100 km^2. Natural reseeding and sprouting from stumps and rhizomes simply will not occur fast enough at this areal scale to counter the destructive impacts of erosion and mass wasting. The vulnerability to erosion from these treatments also makes them undesirable for contaminant demobilization; it makes little sense to use a treatment which is ineffective and causes great environmental damage.

Three treatments are benign, or perhaps beneficial, to coniferous forest: barriers (treatments 3-1 and 3-2) and application of sewage sludge (treatment 5-0). Sludge application may be effective in demobilizing a contaminant, and therefore is a preferred treatment, especially in sensitive areas where low-level contamination has occurred; however, the possibility of contaminant entry into the food chain must be evaluated prior to its use.

The next group of relatively benign treatments includes clearcutting (treatment 1-2), stumping and grubbing (treatment 1-3), and shallow and deep plowing (treatments 1-5 and 1-6). Deep plowing and stumping and grubbing have greater impact at the scale of 100 km^2 for the same reason as chemical stabilization, namely that colonizing vegetation is usually overwhelmed by erosion in the first few seasons after treatment. Surface scraping and grading (treatment 1-4) has greater impact at the 10- and 100-km^2 scales than over smaller areas because the treatment accelerates erosion while, through topsoil removal, intrinsically decreasing the rate of revegetation.

Finally, the group of treatments which involve chemical stabilization and soil removal, treatments 2-6 and 2-8, have serious, though not drastic, impacts on coniferous forest associations. Quantitatively and qualitatively, their short-term effects and effectiveness are identical to their counterparts (treatments 2-3 through 2-5) which involve mechanical, rather than chemical, stabilization. The difference is that most chemical stabilizers do not compact the soil to produce an environment hostile to seedling growth, but they do effectively retard erosion while vegetation establishes itself. By the time the stabilizer breaks down, in one to five growing seasons, vegetation will be firmly established and will continue to retard erosion as the chemical stabilizers decompose. This is true, in most cases, even over large areas, although more durable stabilizers should be chosen to give plants more than one season to become established over large areas.

4.7 CONCLUSIONS

The treatments which will have the least, and approximately equal, effect will be exclusion by barrier (treatment 3-1 and 3-2) and sewage sludge application (treatment 5-0). These treatments may have a beneficial effect on the development and perpetuation of the climax association. Among the treatments which require the removal of the forest, recovery would be most rapid with clearcutting (treatment 1-2) and shallow plowing (treatment 1-5), with stumping and grubbing (treatment 1-3) and deep plowing (treatment 1-6) having slightly longer recovery periods only at the 100-km^2 scale.

All of these treatments would be acceptable. In cases other than low-level contamination, restriction by barriers should be used only in remote areas, because barriers provide no significant, immediate demobilization to a contaminant.

Treatments involving mechanical compaction (treatments 2-3 through 2-5) and paving (treatment 4-0) would have severe impacts over all areas. These treatments should be prohibited at all scales greater than 1 km^2, and should be used over smaller areas only in the case of contamination severe enough to prohibit the use of less damaging, though highly effective, techniques such as those involving chemical stabilization (treatments 1-1, 2-6, 2-7, and 2-8). Soil cover (treatments 1-7 and 1-8) should be used only for contaminants which would naturally degrade before natural erosion removes the soil cover. The exact determination of the proper treatment must be made considering the quantity and quality of released contamination, as well as the proximity of the site to human populations and activities.

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CHAPTER 5
AEOLIAN MOUNTAIN PEAKS

5.1 OVERVIEW

The discussion in this chapter will largely be restricted to high mountain regions and peaks that lie above the tundra life zone, but much of the material may be applicable to desert mountains of much lower elevation and the barren peaks and outcroppings of forested mountain ranges. Generally, the environments to be considered herein consist of steep slopes and barren rock; depending upon the altitude and latitude, ice and snow and harsh meteorological conditions may be present, unmitigated by the protection of vegetative cover. Depending upon geographic location, tundra, desert and various forest life zones surround the mountain peaks at lower elevations, frequently in close proximity. Because of the fact that the surrounding life zones are a priori "downstream," it is likely that cleanup operations may ultimately involve more than the primary site of a spill, if such is a mountain peak. If containment or stabilization of a spill on a mountain top is not effected by the cleanup procedures implemented, the discussions in the reports for other life zones will become applicable at lower elevations. It should also be noted at the outset of this discussion that probably few, if any, of the cleanup procedures covered in this series of reports will be either effective or logistically possible on many mountain peaks due to the severity of the physiographic and meteorological components of the environment.

5.1.1 The High Mountain Peak Environment

The vegetational zonation found in mountain ranges varies largely with the latitude, altitude, slope aspect, mass of the mountain range, prevailing wind patterns and the location of the range with respect to land and oceanic masses. These factors are discussed in some detail in the coniferous forest chapter.

Life zones in the uppermost mountain regions of the world have been described by Whittaker[43] as arctic-alpine desert and semidesert. The semidesert occurs in arid regions above the timberline. In temperate zones, sparse communities of low shrubs and/or cushion plants may occur. In the arctic, the semiarid areas are generally considered to be part of the tundra zone, but with respect to physiognomy, plant adaptations, soil characteristics and sparseness of animal life, they are desert-like. Arctic-alpine deserts tend to have very low plant cover, dominated by snow, ice or rock which may support growth of bacteria, algae and lichens. Vascular plants may occur in irregularly scattered pockets having less extreme microclimates. These deserts occur in Greenland, Antarctica, and above timberline on high mountains all over the world. Alpine deserts occur in the lower alpine zone in arid mountain ranges. At lower latitudes, permanent ice and snow are not necessarily present, and the presence and nature of vegetation will vary with the amount of moisture present.

Swan[38] notes that the alpine regions of the world are delimited by timberlines extending from latitudes 72°N to 56°S with a maximum altitudinal extension to approximately 14,000 ft. Figure 5-1 depicts the worldwide distribution of timberlines and the arctic and aeolian zones. The upper edge of the alpine zone is usually defined as the upper limit of the range of vascular plants. Here too occurs an upward transition from autotrophic to heterotrophic life forms. The characteristics of this boundary identify three basic types of alpine regions: high-latitude, low-latitude and a depressed equatorial alpine region. In the low latitude alpine environment, vascular plants are found above 20,000 ft. (6,100 M) and a long growing season is typical.

Above the alpine zone lies the aeolian zone which Swan[37] has divided into terrestrial, nival and aquatic phases. In the aeolian zone, autotrophic algae, lichens, mosses and a variety of heterotrophic animals and plants occur, but vascular plants are entirely absent except in isolated instances where microhabitats exist which provide more favorable circumstances. The aeolian zone extends in altitude to include the summit area of Mount Everest where bacteria, fungi and yeasts are found. Figure 5-2 illustrates alpine-aeolian zonation in the eastern Himalaya.

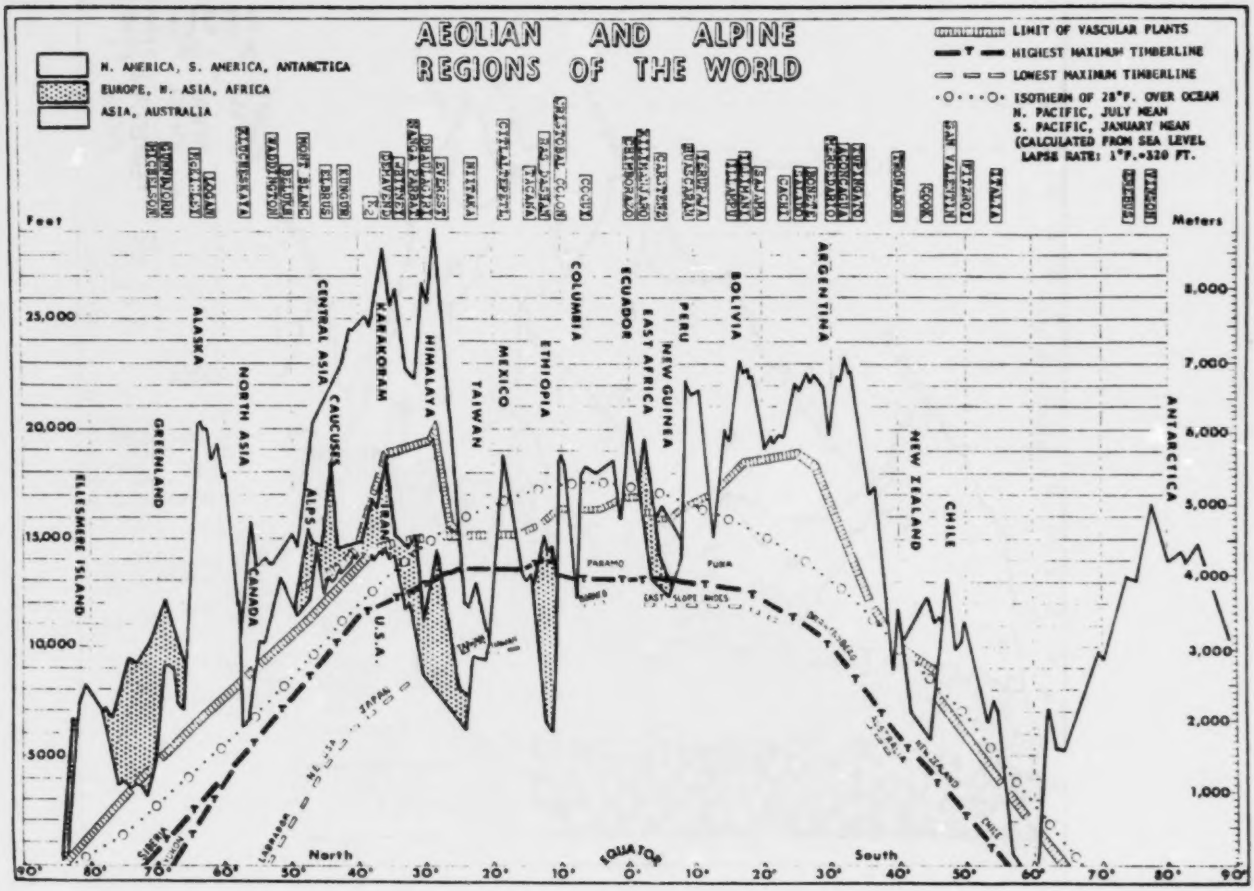
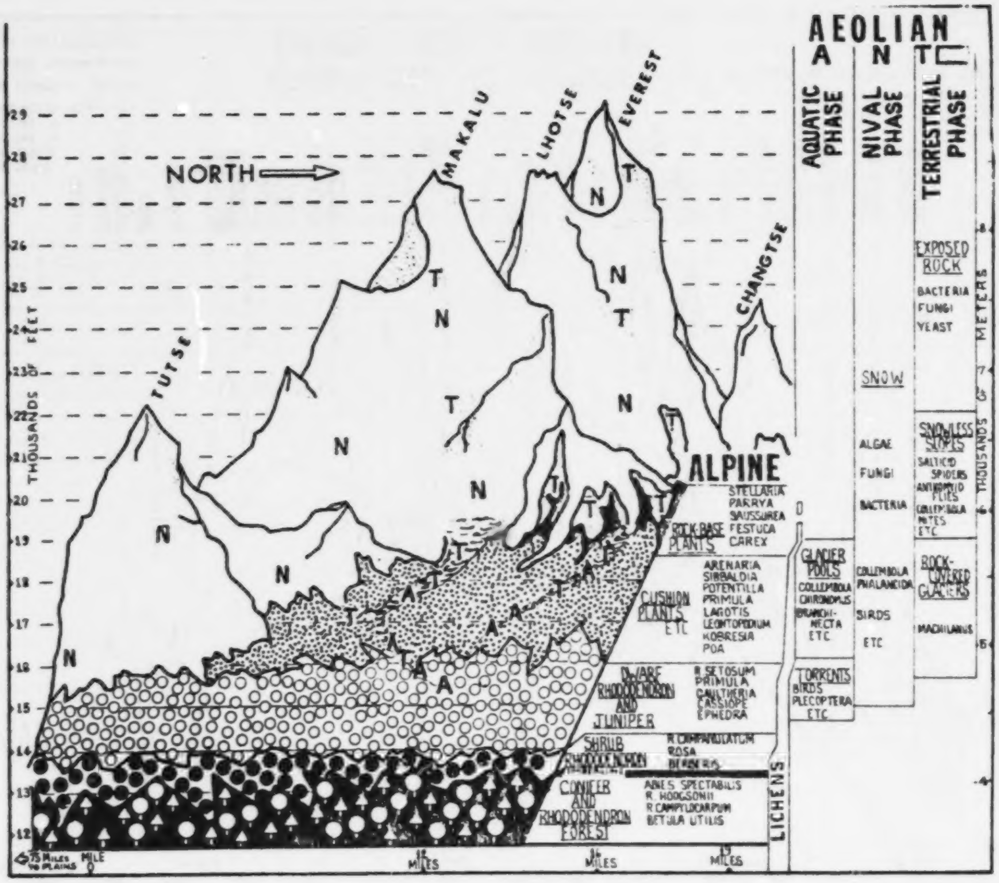


Figure 5-1. Alpine and aeolian regions of the world (from Swan[38]).


AEOLIAN
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THOUSANDS OF FEET
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EXPOSED ROCK
BACTERIA
FUNGI
YEAST
SNOW
SNOWLESS SLOPES
SALTICID SPIDERS
ANTHOMYIID FLIES
COLLEMBOLA
MITES
ETC
ALGAE
FUNGI
BACTERIA
STELLARIA
PARRYA
SAUSSUREA
FESTUCA
CAREX
ROCK-BASE PLANTS
GLACIER POOLS
COLLEMBOLA
CHIRONOMUS
BRANCHINECTA
ETC
COLLEMBOLA
PHALANGIDA
BIRDS
ETC
ROCK-COVERED GLACIERS
MACHILANUS
CUSHION PLANTS ETC
ARENARIA
SIBBALDIA
POTENTILLA
PRIMULA
LAGOTIS
LEONTOPODIUM
KOBRESIA
POA
TORRENTS
BIRDS
PLECOPTERA
ETC
DWARF RHODODENDRON AND JUNIPER
R. SETOSUM
PRIMULA
GAULTHERIA
CASSIOPE
EPHEDRA
SHRUB RHODODENDRON
R. CAMPANULATUM
ROSA
BERBERIS
CONIFER AND RHODODENDRON FOREST
ABIES SPECTABILIS
R. HODGSONII
R. CAMPYLOCARPUM
BETULA UTILIS
LICHENS
75 MILES TO PLAINS
MILE 0
12 MILES
16 MILES
19 MILES

Figure 5-2. Alpine-aeolian zonation in the eastern Himalaya (from Swan[38]).

Most of the work on high-mountain ecology has been done in Europe and in North America; a considerable amount of work has also been done in the Soviet Union. Swan[38] notes that unifying concepts need to be developed in order to link the ecological characteristics of the widely spread treeless mountain zones throughout the world that are commonly lumped under the category of "alpine." For example, in the eastern Himalaya, the life found above the level of the highest vascular plants forms a distinct category.

5.1.2 The Aeolian Life Zone

In the aeolian zone, nutrients are supplied by the atmosphere (carried in by wind). Swan[38] has distinguished between the aeolian and alpine regions by contrasting the sources of nutrition: alpine biota are dependent upon local autotrophic flowering plants, whereas aeolian organisms are basically supplied by air-transported nutrients that are rarely of local origin. Hutchinson[19] considers the aeolian region to be roughly equivalent to the hyperallobiosphere or that portion of the eubiosphere at high altitudes where heterotrophic organisms are dominant.

The aeolian and alpine regions may be defined geographically as well as nutritionally and include some portions of the high alpine zone and the nival zone described by European researchers.[23] Swan[38] believes that the aeolian region is most easily recognized where established or semipermanent organisms exist in the absence of flowering plants. Vascular plants may be absent at lower altitudes in particular localities or seasons, and when the ground is covered with snow and organisms dependent upon snow and wide-blown nutrients, the distinction may become blurred. Swan[37] suggests that the picture may be simplified if the aeolian region is arbitrarily defined as being near or above the upper limits of flowering plants.

Nutritional patterns in the aeolian zone are still not completely understood. Animals are sometimes found at altitudes far above the highest vascular plants; in such instances, wind-blown nutrition is ascribed. Also, insects and crustaceans occur in temporary glacial pools, and it may be inferred that those organic nutrients present are probably of atmospheric origin, falling on old snow fields and eventually being released from melting ice. Arthropods and birds that feed upon wind-blown insects are obviously aeolian, but they may be transient visitors to the zone. In many, perhaps most, instances the type and quality of nutrients involved in the support of aeolian life and the degree to which animals and plants are dependent upon atmospheric nutrition are unknown. Gregory[16] has reviewed various organic particles carried by the atmosphere such as pollen, bacteria, fungi and insects. Luty and Hoshaw[22] have examined airborne dissemination of green algae. Swan[38] has reviewed the ecology of the three phases of the aeolian zone (nival, aquatic and terrestrial); a brief adaptation thereof follows.

5.1.2.1 The Nival Phase of the Aeolian Zone--

Descending air over snow fields may have the effect of concentrating particles suspended in the atmosphere; hence, analysis of snow fields may provide an exaggerated impression of the distribution of airborne debris. Windblown particles tend to blow on and off of most surfaces, but remain upon snow. Osburn[30] studied the phenomenon of the accumulation of radioactive fallout contamination of snow; he found that the particles concentrate in a snow patch as it melts, presumably as a function of adsorption of the particles to surfaces within the snow. Interestingly, radioactive debris was held to a large extent within a shrinking snow patch and was released in reduced quantities in the melt water. He also noted that radioactive particles tend to concentrate in soil depressions beneath melting snow. These observations may be of potential significance in the design of alternative cleanup procedures for implementation in the high mountain environment.

Autotrophic green and bluegreen algae may be considered to be of an aeolian nature in the high mountain environment in that nitrogen and other nutrients must be derived from the atmosphere. Bettler[7] has suggested the existence of a food chain consisting of pollen > bacteria > algae > annelids for the green snow worm Mesenchytraeus solieugus that occurs on a British Columbian glacier. These aeolian annelids are found in the mountains of the northwestern United States, Western Canada and Alaska.

There has been some work suggesting the possibility of organic precipitates and proteinoid materials of oceanic origin being deposited upon high mountains, but Swan[38] believes that further study is necessary on this topic. Accumulations of dead insects are occasionally found at high elevations, and these are scavenged by certain species of birds. As previously mentioned, Osburn[30] found that radioactive particles concentrate in soil depressions beneath melting snow; it is also possible that this is true for organic materials.

5.1.2.2 The Aquatic Phase of the Aeolian Zone--

The organisms that inhabit the pools and torrents of the aquatic phase of the aeolian zone are considered to be aeolian by virtue of the fact that the organic materials upon which they subsist are assumed to be originally of atmospheric derivation. Torrential fauna include turbellarians, crustaceans, hydracarinids, and various insects that inhabit areas primarily or solely near the sources of torrents or those whose primary nutritional source is closely linked with organic materials released from snow or ice. Large populations of fairy shrimp (Branchinecia sp.) are found in temporary glacial pools at altitudes up to 19,000 ft. in the eastern Himalaya. Examination of their intestinal contents has revealed mostly fine granular glacial dust mixed with traces of an unidentifiable organic material; algae have not been found. That algae are found in more permanent ponds suggests the existence of nutrients derived from autotrophic plants, but if, in fact, the primary algae are green algae, the presence of nitrogenous material derived from the organic debris of snow may be inferred. Swan[38] believes that many lakes classified as alpine are, in fact, aeolian.

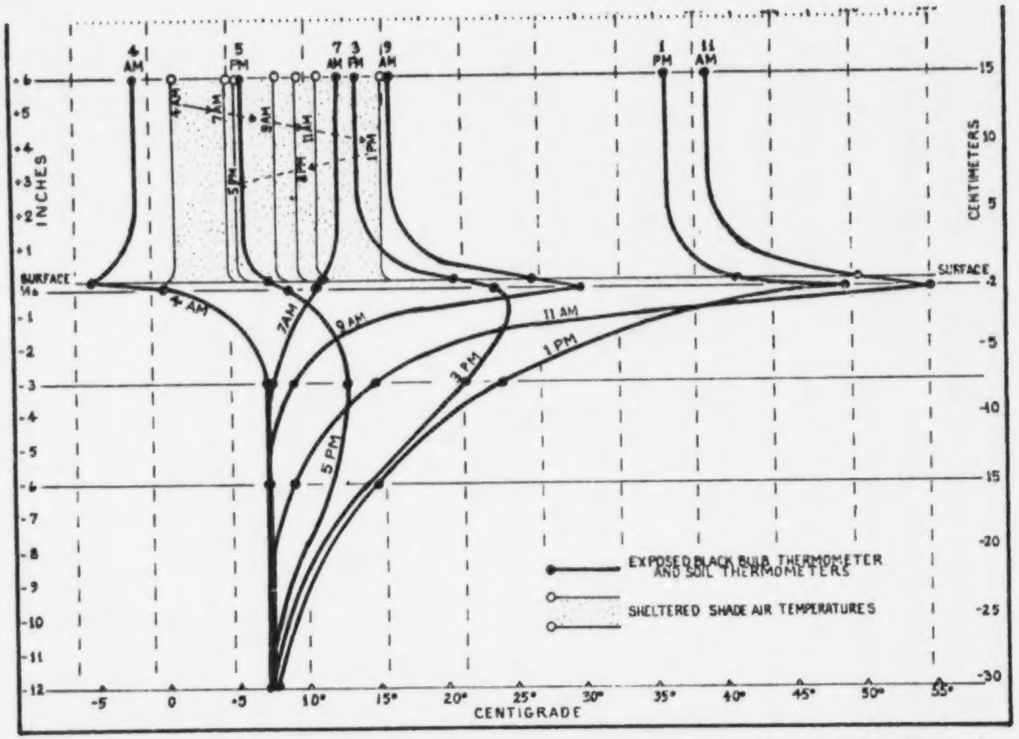
5.1.2.3 The Terrestrial Phase of the Aeolian Zone--

The organic and other particulate matter that is deposited upon high altitude snow and ice surfaces also deposits and collects upon snowless areas, the particles being trapped within cracks and crevices where air turbulence is reduced and the particulate contents of the air can fall out. Such accumulations of the terrestrial phase are frequently obvious and largely account for collected dust under rocks on mountainsides. Rock slopes free of snow harbor more scattered and thicker accumulations of debris than snow-covered slopes; such concentrations serve to sustain aeolian organisms. It is likely that such sites will also trap spilled materials that are not blown off rocky mountain top surfaces.

Terrestrial aeolian animals are frequently found at lower altitudes on rock-covered glaciers. Various spiders, mites, and insects have been found in this environment in the Himalaya. Mites, collembolans and flies live in the absence of plants on the snow free slopes on the sides of glaciers; their nutrition is aeolian in nature. Salticid spiders (Europhrys sp.) have been found at 22,000 ft. (6700 m) in the Himalaya and are presumed to feed upon collembola, anthomyid flies and possibly wind-blown insects. An example of this aeolian food source may be seen on the peak of Citlaltepetl (Pico de Orizaba) in Mexico where July winds are from the east with a sweeping uplift of air from the tropical valleys of Vera Cruz onto the mountain peak; many insects are transported to the peak by these winds. The lizard Sceloporus microlepidotus Wiegmann is relatively abundant on rocky slopes above timberline[36] and is found at 15,800 ft. of elevation (700 ft. above the highest flowering plants). The lizard colonies are visited by ravens (Corvus corax sinuatus Wagler) and sparrow hawks (Falco sparverius sparverius Linn.). Salamanders (Pseudoeurycea gadovii) were collected at 15,000 ft. and rattlesnakes (Crotalus triseriatus) at 14,850 ft. Swan[38] suggests that all of these organisms exist, at least partially upon the aeolian food chain. Lizards have also been found at extreme elevations in Peru and Nepal.[38]

The upper limit of the terrestrial phase of the aeolian region is uncertain. Swan[38] notes that sun/shade temperature differentials of 43°C (78°F) are found between shade and sun near the ground at altitudes of 15,500 ft. He suggests that it is at least plausible for such differentials to exist at higher altitudes, perhaps even near the summit of Mount Everest, in micro habitats sheltered from high wind velocities. Assuming a lapse rate of approximately 3°F per thousand foot increase in elevation, minimum shade temperatures near the summit of Mount Everest would approximate -9°F (-23°C), and maximum shade temperatures would approach 20°F (-7°C). Based upon data from free-air temperatures and comparative temperatures between snowless valleys and snow-covered slopes, Swan[38] suggests that actual shade temperatures near the summit of Mount Everest are somewhat colder, but even if shade temperatures approximate -30°F (-33°C), it is conceivable that on calm days, surface sun temperatures may approach 50°F (10°C). The fact that icicles exist where snow overlies dark vertical rocks at extreme altitudes indicates the occurrence of above freezing temperatures. Figure 5-3 indicates the sun/shade temperature ranges occurring at 15,500 ft. of elevation for soil and air in a valley in eastern Nepal.

Swan[38] lists a number of bacteria, fungi and yeasts that were collected by the 1963 American Mount Everest expedition. He suggests that periodic equable temperatures and water are available at high altitudes; the fact that the organisms obtained on Mount Everest represent soil microflora rather than a



Temperature profile of the soil and lower air: May 23, 1954, 15,500 ft (4724 m), Barun Valley, East Nepal. Temperatures were obtained on a level surface near prostrate plants (*Potentilla* sp., *Sibbaldia* sp., etc.). The soil was sandy but brown with humus. May 23 represented a relatively warm day. The effect of the sun was apparent at 9 A.M. Clouds intervened prior to 3 P.M., and full shade occurred before 5 P.M. Wind velocity was estimated at less than 10 mph. Temperatures at 1/16 inch below the surface were obtained by placing the thermometer on its side just under the surface so that a minimum thickness of soil intervened between the thermometer and direct sunlight. The black-bulb thermometer was an ordinary thermometer with the bulb painted with India ink.

Figure 5-3. Diurnal sun/shade temperature ranges in air and subsurface soil at 15,500 feet (from Swan[38]).

miscellany of air-borne organisms supports the thesis that living organisms do exist and grow on very high mountains.

Lichens are widespread in the alpine zone and are often found at higher altitudes than are local vascular plants, but they are relatively scarce in extremely arid environments or on surfaces recently uncovered by permanent snow. In eastern Nepal, certain vascular plants that can obtain water from the soil exist at higher elevations than do the noticeable lichens. That lichens can grow upon glass and smooth rock surfaces without leaving any trace of etching is suggestive of their aeolian nutritional status. Lichens are known to be sensitive to smog and to concentrate radioactive fallout.[31,38]

Although lichens are scarce at the high elevations of the aeolian mountain zone, they do constitute the most visible of the plant life forms in this zone; therefore, it is of interest to consider their ecology in greater detail. Hale[18] states that lichens occur in virtually every pioneer terrestrial habitat from antarctic and arctic to tropical areas. Their ability to adapt to xeric environments permits them to dominate in certain habitats that are devoid of other plant life forms. Generally, lichens have a high light requirement and they are succeeded by bryophytes and higher plants where they are shaded and other conditions permit such successional growth. However, in habitats where conditions are relatively stable as in the Arctic and Antarctic, in deserts, and rock outcrops, lichen communities can persist for centuries. Hale notes that various lichens tend to be specific for certain rock types. Mattick[27] states that lichens have been found as high as 6200 m (20,341 ft.). Gams[14] has reported lichens at 7000 m (22,965 ft.) on K-2 in Karakonm. Kappen[20] states that lichens are often the predominant form of vegetation in mountains of northern regions such as Scandanavia, but many species demonstrate reduced vitality above 5200 m (17,000 ft.).

Swan[38] ascribes the scarcity of lichens at high elevations to lack of surface water from snowmelt, or possibly to snowblast. Below 5750 m (18,864 ft.), subsurface liquid water from snowmelt permits the development of small "oases" of vascular plants in the scree.[8] Here (in what is, strictly speaking in view of our working definition of the aeolian zone, an upward extension of tundra), lichens are found entangled with small herbaceous plants. The relative aridity of the area confines the vascular plants to portions of scree slopes with underground meltwater sources, or to rock-base niches.[8] Lichens, lacking a vascular system and roots, are unable to utilize subsurface water, and therefore are limited by the degree of aridity of the particular mountain environment.[20]

Swan[38] has noted that studies of barren areas of the world, notably those of the antarctic, give little consideration to airborne nutrition. Llano[21] has discussed the contribution of wind-blown guano to populations of collembola and mites found within a few hundred miles of the South Pole.

In order to provide a basis for estimation of time to recovery from a clean-up operation, it is of interest to briefly consider the nature of lichen growth. Armstrong[2] has reviewed studies on the growth rates of lichens. Lichen colonies do not have a steady growth rate; initial growth is slow, until a diameter of approximately 1-1.5 cm is reached at which time the rate increases and becomes nearly linear until a diameter of 12 cm is attained and then the rate slows, becoming non-linear. Studies under more ideal growth conditions than those obtaining in the aeolian mountain peak environment indicate thallus (plant body) diameter growth rates (in the rapid linear growth phase) ranging from 1.5 to 3.0 mm per year for the lichen Parmelia grabratula. A study of maximum thallus diameter versus thallus age indicates that nearly 25 years are required for the lichen to attain a diameter of one centimeter, then (at an increased rate of growth) a diameter of 7 cm may be reached after fifty years. Armstrong[2] suggests that there is considerable variation in the growth rate on an individual plant and that the rate is quite sensitive to environmental factors. Hale[18] notes that while lichens with diameters of 30-40 cm have been reported in the Arctic and are reputed to be several thousand years old, only direct and continuous observation can establish the true age of a lichen thallus. Hale lists growth rates for several species; one is reported to have an annual radial growth rate of 25 mm and another ranges from 11 to 90 mm. Growth rates for a given species increase with the temperature of the local climate. Hale believes that the average life span of a given lichen thallus may range from 20 to 40 years, depending upon species and conditions. In the foliose lichen Parmelia conspersa, growth slows after a thallus diameter of 9-10 cm is reached, following which the center decays and is overgrown by crustose lichens. These crustose lichens also overgrow freshly exposed rock surfaces where the centers of the thalli have fallen away. Hale is of the opinion that such "recycling" of a lichen community can continue until the micro-environment is so altered that other plant forms succeed the lichens. Since the last glaciation of North America and Europe some 10,000 years ago, such recycling of lichen communities may have occurred hundreds or thousands of times.

There are several methods of measuring and expressing lichen growth rates, none of which are entirely satisfactory. Armstrong[2] suggests that when the problems of such measurements are solved, the science of lichen ecology will be able to progress rapidly. If the diameter and radial growth rate can be accurately determined, it becomes possible to estimate the age of a colony, but, according to Armstrong, there are currently several problems with such determinations. This "state of the art" probably partially explains the absence of growth data on lichens in the aeolian mountain zone.

Bailey[6] states that there have been few studies in which the germination and development of lichen propagules (bodies containing the algal and/or fungal spores which are disseminated by wind, water, animals, etc.), on substrates conducive to lichen growth. Lichens are structures composed of both fungi and algae in a symbiotic relationship. They produce propagules containing either or both symbiotics, but only the latter type can reproduce the lichen structure. Propagules are dispersed by wind and Bailey cites studies indicating that the propagule content of the wind is proportional to the regional abundance of lichens. Bond[9] found that glacial ice in Colorado contains arctic-alpine lichen spores that are presumably aeolian in derivation. Once a spore has been deposited on a suitable substrate, it must germinate and then attach itself to the substrate by the formation of a "holdfast." Thallus fragments of preexisting plants can also become established on a new site by the formation of a holdfast. Different species of lichens vary in the types of spores that are formed.

Bailey[6] notes that little is known of the nature of colonization of newly exposed surfaces, partially due to the relative scarcity of such areas. It was found that the island of Krakatau was colonized some 3 years after the volcanic eruption, which removed all plant cover, by blue-green algae; lichens followed at a later stage. Studies on Surtsey, a volcanic island which appeared off the southwest coast of Iceland in 1963, indicated the presence of three species of lichens by 1970 and 11 species by 1973. Four of the species were widespread and evenly distributed over the island. Aeolian transport is ascribed to these botanic colonists. The lichens first became established in and around holes in the lava, suggesting that surface texture was important in providing a "foothold" for the holdfasts of the plants.

Based upon the foregoing discussions, it would appear that lichens are able to colonize a new area within a 10 year period of the first exposure of the substrate surface, but development of the plants is a slow process, requiring 50 years to attain a diameter of 7 cm and perhaps 80 to 100 years to "mature" to a diameter of 12 cm. These estimates are based upon the results of studies in more temperate environments than that which obtains in the aeolian mountain peak zone; here, conditions are more severe, and the time to recovery may be markedly increased.

The time required for recolonization of a treated area will depend upon the extent and nature of the treatment, and the abundance of lichens surrounding the treatment area. If viable fragments of lichen thalli survive treatment which includes the removal of the lichens, the rate of recolonization may be relatively rapid and independent of the size of the treatment area. If no viable thalli fragments or propagules survive a treatment, colonization will have to come from outside, and will probably be slower for a large treatment area than for a small area. It should be emphasized that this brief review only skimmed the surface of lichen biology and ecology, and that many important aspects of their developmental patterns were not discussed. Further, no data were found for environmental conditions comparable to the aeolian mountain zone.

Swan suggests that the reestablishment of life forms in areas uncovered by permanent snow may require considerable time and that aeolian forms are successional to alpine flora and fauna in environments capable of supporting alpine life forms.

5.2 NATURAL PERTURBATIONS

Only aeolian life, as discussed earlier in this chapter, will be considered here. There is little precedence for intentional perturbation of high mountain peaks and relatively little literature concerning either natural or intentional perturbations. Also, in the discussions of other life zones, steep slopes per se were considered only incidentally.

The lack of vegetation and the steep slopes characteristic of high mountain peaks make them particularly vulnerable to the erosive forces of earthquakes, wind, water, ice and associated debris. Meltwaters and rainfall wash soil away, leaving rills behind. The steepness and shape of a slope strongly influence the velocity and destructive force of water runoff. High mountains tend to have steep slopes with an average gradient of 25° or more.[1] The gradient is a function of various factors, including the type of rock present, the age of the mountains, their tectonics, climate, etc. Soil destruction also is a function of the shape of the slope, the relative positions of sections with different gradients and the nature of the soil formation; for example, podzolic soils, formerly under forest, are particularly vulnerable to erosion.[1] Animal grazing activities also serve to erode mountain slopes as well as enhance conditions for water and wind erosion.

The hydrographic networks of mountainous regions are complicated systems composed of rivers and streams of various sizes, gullies and ravine type gorges, all of which usually terminate in larger mountain rivers. Al'benskii and Nikitin[1] have discussed these systems with respect to various aspects of mountain system erosion. They note that the conditions of headwaters of rivers serve to determine the role of rainfall in feeding the rivers. In high mountains, the role of rainfall is negligible; snow is the major source of runoff. Groundwater provides approximately one third to one half of the water of mountain rivers. Rivers originating from glaciers and snowfields have fairly regular rates of flow, whereas those originating below the snowline frequently run dry in the summer. Where forestation is light or absent, the rate of runoff increases rapidly and the rate of decrease is only slightly less; heavily forested areas usually do not have sharp runoff peaks.[1]

5.2.1 Erosion and Mudflow Phenomena

Al'benskii and Nikitin[1] observe that the greatest force of linear erosion in mountains is exerted by small rivers and streams, and temporary torrents, particularly in periods subject to strong showers and/or intensive snowmelt. Such torrents are known as mudflows (or mud-stone flows) and are loaded with silt, sand, debris, stones and other solid material. The character of the flow is influenced by the degree of solid material loading; if there is little solid material present (a fluid or turbulent mudflow), the flow resembles a freshet, but if the water is heavily loaded (a cohesive or structural mudflow), the movement of the flow may be greatly slowed.

Cohesive mudflows have a high specific gravity and tremendous destructive force derived from flow pressure and shocks from stones carried by the flow. Such flows tend to congeal, forming a wave-like elevation when their movement stops. Fluid flows tend to be contained within the action section of the stream bed, depositing and, to some extent, sorting their solid contents. Mudflows may also be classified according to their origin, e.g., fed by slope erosion and weathering products, fed from linear sources, etc. In arid mountains, the drainage areas of mudflows may contain great reserves of solid material and strong showers may produce highly destructive mudflows.

Mudflows may reach volumes exceeding those of freshets by a factor of 30 or more. Table 5-1 provides data from mudflows in the Soviet Union.[1] Mudflows have been known to carry rocks of 100 cubic meter volume for considerable distances. Mudflows are characterized by episodic activity, being common in some regions and irregular in others. Mudflow velocities vary from 3-7 m per second and tend to proceed in waves of varying height and frequency. Waves are caused by obstructions in the path of flow. Erosion by mudflow is a widespread phenomenon on mountains, but flows are rare in densely forested areas.[1] Owens[32] has studied the morphology of alpine mudflows.

Should an uncontained or unstabilized spill be washed from the primary site, the inclusion of radioactive material in a mudflow is a possibility.

5.2.2 Snow Avalanches

Al'benskii and Nikitin[1] note that snow avalanches are most frequent in high mountains, but they do occur occasionally on medium and low ranges. Avalanches tend to form where large masses of snow accumulate on steep slopes or along ravines. Three types of avalanches may be distinguished on the basis of their formation: surface, bottom and jumping. Surface avalanches are actually snowslides coming off an entire surface of a steep slope; they are common on smooth grassy slopes and are more frequent on slopes facing the sun. Bottom or trough avalanches form in ravines and hollows and slide in the shape of a talus fan. Jumping avalanches differ in that they form in ravines or other surfaces terminating in high escarpments from which the sliding snow "jumps." Avalanches are capable of producing severe destruction, averaging 50-60,000 tons in weight and slides of 1.5 to 2 million cubic meters have been observed. Avalanches tend to flow from slopes of 30° gradient or more, although some have been observed on slopes of 15-18°. Generally, avalanches do not form in densely forested stands. Schaerer[34] discusses the effects of terrain and vegetation upon avalanche sites. An excellent reference to the physics, ecoloy and management research of avalanches may be found in Perla and Martinelli.[33]

Table 5-1. Movement of mountain detritus within measured mudflows as examples of erosion (from Al'benskii and Nikitin[1]).

Name of Stream	Approximate drainage area of the mud-flow, km^2	Solid material transported 1000 m^3	Material removed, average in m^3 per 1 km^2	Content of detritus by weight, %
Malaya Almaatinka (Kazakh SSR, 1921)	60	3,000	50,000	37.0
Kish-chai (Azerbaidzhan SSR, 1936)	25	2,175	87,000	68.2
Gedar (Armenian SSR, 1946)	30	500	17,000	49.0

5.2.3 Landslides

O'Loughlin[29] has studied factors affecting the incidence of landslides. He found that a combination of steep slopes, heavy seasonal rainfall and an impermeable till substratum predisposes a site to catastrophic failure. The occurrence of springs at the heads of landslide scars suggests the importance of groundwater in the release of materials for slides.

Dingwall[11] has found that erosive overland flow of debris and fine sediments from bare debris surfaces is greatest during summer months. This process is limited: to those months when the debris is snowfree and unfrozen; to those surfaces unprotected by vegetation and coarse debris; and to finer fractions of the debris.

5.2.4 Overgrazing

Overgrazing is a cause of soil destruction on mountain slopes; while there is no forage in the aeolian zone, the topic is included here as a perturbation affecting high mountain slopes. Animal grazing trails criscross in increasing density with time, resulting in vegetation removal and soil destruction. Continued use of the trails inhibits regrowth of vegetation. Where the trails merge, sheet erosion can reach proportions of as much as 100 cubic meters of soil per hectare per year.[1]

5.2.5 Recovery

Recovery, either unassisted or assisted, from perturbations in the mountaintop environment does not have the same meaning as in the sense of the discussions covering other life zones. In cases where perturbations such as rock, mud, snow, or ice slides erode barren mountain peaks or slopes, devoid of higher forms of vegetation, the term "recovery" seems to have little meaning. In lower life zones, recovery refers to restoration of the original life forms such as forests or grasslands, but in the aeolian environment where the only life forms are microorganisms, lichens, insects, and a few incidental animals, there is little to restore. Erosion, either violent or gradual, must be considered as a natural process of wearing down mountain ranges. At lower elevations where life zones other than aeolian are present, the term recovery regains its significance and the reader is referred to the appropriate chapters of this series.

However, while recovery is not an applicable term, prevention or reduction of the severity of certain perturbations of mountain environments may be both possible and desirable. With respect to transuranic spills and cleanup, certain preventative measures may aid to reduce spread of the spilled material. This concept will be discussed at greater length in a later section. It is of interest here, however, to note that some success has been encountered in the reduction of the incidence and/or severity of avalanches, erosion and mud flows through afforestation. Afforestation is certainly not a short-term procedure, but it may have some applicability with respect to treatment of transuranic spills. Discussions of afforestation at lower elevations in the aforementioned context may be found in: Al'benskii and Nikitin;[1] Margaropoulos;[24] Aulitzky;[4] Martinelli;[26] and De Quervian and Der Gand.[10]

Al'benskii and Nikitin[1] discuss the topic of afforestation as a possible means of reducing mudflows and avalanches. Aulitzky[4] notes that in many cases, timberlines lie below altitudes where tree growth is climatically possible and he discusses the possibility of afforestation above present timberlines. Martinelli[26] lists possible methods of snowpack and avalanche control: weather modification by cloud seeding; intentional avalanching for the purpose of storing snow in shaded valleys at high elevations; reshaping of natural terrain to improve show trapping efficiency and capacity; control of snowmelt by addition of materials to the snow surface; and the erection of snow fences and other barriers to increase snow accumulation in desired areas. Dortignac[12] discusses the possibility of increasing the melt rate of glaciers and packed snow by scattering dark materials over the surface.

5.3 MAN-MADE PERTURBATIONS

No precedents were found in the literature for intentional perturbations of mountain peaks in the aeolian life zone; however, perturbations of mountain peaks and slopes at lower elevations are common in the form of plowing and recontouring for strip mining and agricultural purposes; these perturbations may occur in desert mountains which have certain similarities to the aeolian zone with respect to the absence of vegetation.

5.3.1 Regrading and Replanting

May and Striffler[28] discuss regrading and revegetation of mountain watersheds sustaining severe mechanical and hydrological disturbances due to strip mining operations. Al'benskii and Nikitin[1] discuss increased erosion due to agricultural efforts on mountain slopes, and methods of afforestation of these damaged slopes by terracing and replanting.

5.3.2 Alternative Techniques

The aeolian mountaintop environment presents unique logistical problems for cleanup that are not present in other terrestrial environments. As discussed earlier, the potential for immediate and possibly widespread dissemination of spilled material by wind and water is great. Possibly, the first problem to be addressed will be that of containment rather than cleanup. As noted in the foregoing section, most of the treatments considered for other terrestrial environments will not be applicable to mountain peak spills. They might, however, become applicable if an uncontained spill spreads; the contamination of streams, lakes, and mudflows presents a definite hazard. The derivation of possible substitute treatments is beyond the scope of this report, but certain observations are pertinent.

It is important to note that wind is an important component of the high mountain macroenvironment in the aeolian zone. Life forms that are adapted to an existence based upon the providence of the windfall most likely will be more abundant in sheltered microhabitats where windborne debris can settle out of suspension. This precipitation process will include atmospheric contaminants. Osburn[31] has noted that lichens collected in areas adjacent to the Greenland "Broken Arrow" incident contained higher than background contamination.

Various aspects of the physics and management of snow and ice are discussed in Martinelli,[25] Dyunin,[13], Gary,[15] Shiotani and Arai,[35] Tabler,[39,40] Tabler and Schmidt,[41] and Perla and Martinelli.[33] An important factor in the treatment of a spill in the aeolian zone will be whether the spill occurs on a snow-covered surface, soil surface, or rock surface. The observation of Osburn[30] that snow adsorbs and concentrates particulate matter can be of extreme importance for the design of effective containment and cleanup procedures. The combined actions of water and gravity, which present the immediate danger of spread of the spill to lower levels on the mountain, might also make possible the utilization of the properties of an affected watershed to concentrate and contain a spill.

Similarly, the effects of wind barriers, serving to concentrate organic and particulate matter in the aeolian environment, might also provide additional possibilities for treatment. Devised techniques embodying these and similar factors might also be environmentally compatible and offer comparatively short recovery times.

The possibility of controlling snow surface temperatures by dusting with various materials has been studied by Arnold,[3] Grove et al.,[17] and Williams and Gold.[44]

It is likely that there will be a degree of similarity between the responses of the aeolian and alpine environments to cleanup procedures. Swan[37] primarily distinguishes between the biological components of the two zones on the basis of nutrition; with respect to the physical phase of the environment, there probably will be a number of similarities in the response of terrain in the two zones to cleanup operations. It should be realized that mountains, particularly the peaks, present a dynamically unstable condition rather than the dynamic equilibria presented by biological systems. Geologically speaking, all mountains are doomed to destruction by erosion; therefore, "recovery" of the physical component of the mountain ecosystem does not have the same meaning that it does in more horizontal situations. At best, "recovery" will imply a return to the pre-treatment dynamic state, or rate of erosion.

5.4 EFFECTS OF CLEANUP PROCEDURES ON AEOLIAN MOUNTAIN PEAKS

5.4.1 Proposed Treatment Techniques

As discussed previously in the section on recovery from natural perturbations, the high mountain peak environment presents a totally different situation from those discussed in reports on other life zones. First, the very nature of what is meant by the term "recovery" is open to question. There are few life froms present to be significantly affected by possible cleanup procedures. There are no flowering plants in the aeolian life zone; life forms present on the high peaks are limited to bacteria, fungi, algae, lichens, insects, nematodes, and a few species of birds and reptiles. Second, the nature of the mountain peak terrain, combined with the lack of flowering plants will make questions concerning recovery from most of the treatments considered in other reports moot: there is virtually no plant life to "recover" and such treatments as vegetation removal, surface alteration, soil removal, plowing, soil fill, sludge application and flooding are either not applicable or, if logistically possible, impractical. It appears likely that alternative and innovative treatment procedures will be necessary to treat primary spill sites, while conventional treatments may be necessary at points below the spill if it is not contained.

While it is true that there is little variety or abundance of life in the aeolian environment, the ecosystem that exists may be considered quite fragile. As previously discussed, it has been observed that lichens are slow to become established on high mountain surfaces that have been uncovered from permanent snow. Those life forms that have become established in the aeolian system are dependent upon accumulations of nutrients that are ultimately derived from the winds; it is likely that the time required for such accumulations to form is rather long. There are very little data on this subject.

An important consideration in the design of cleanup techniques for the mountain peak environment is the accessibility of this zone to men and equipment. The operation of helicopters may not be feasible at higher elevations; ground access to many sites by heavy equipment may be impossible, and the severity of mountain physiognomy may preclude its use. Equipment used in cleanup operations may be restricted to that which can be packed in or parachuted. Air removal of contaminated materials may be the only feasible method. For these reasons, methods based upon (or partially utilizing) the management and manipulation of natural features and phenomena (see discussion of the Nival Phase of the Aeolian Zone) at the site, such as snow cover and water runoff, may be desirable from the standpoints of logistics, economics and ecology. The impact of devices to manage wind, snow drift and water runoff would be variable with their design, construction and placement. It is expected that their major impact would be upon the abiotic phase of the environment (erosion, etc.) and that the impact of such devices upon the life forms of the aeolian zone would be minimal.

The following discussion of suggested cleanup techniques will be generally limited to the aeolian life zone. Some of the comments might also have limited application to steep mountain slopes and peaks in lower life zones or in a desert environment.

(0-1) Natural Rehabilitation

Little has been published on the topic of natural rehabilitation of perturbations to the aeolian mountain peak environment, making the estimation of recovery time from a spill cleanup operation rather difficult. "Natural rehabilitation" would depend largely upon the rates of two processes: dispersion of spilled material by wind and water and the rate of decay of spilled material that becomes trapped in rock crevices, snow and ice. These processes could be quite rapid or very slow, depending upon the properties of the spilled material and climatic conditions at the site.

(1-1) Chemical Stabilization

Soil stabilization by the addition of chemical stabilizers to the surface is probably not a viable treatment in the aeolian mountaintop environment.

(1-2) Clear Cutting Vegetation ("Removal")

This technique, applicable in many life zones, will be generally inapplicable in the aeolian environment. With the exception of lichens, fungi, and certain algal species, there is no vegetation present. The removal of lichens from rock surfaces or algae from cliff faces, snow, or ponds probably will have little lasting impact upon the ecosystem, with the exception that lichens probably will be very slow to become reestablished. It is unlikely that the removal of lichens will have measurable effects upon temperature, radiation, soil moisture, precipitation, or surface runoff. Removal of algae from snow or ice may increase surface albedo, thereby decreasing surface temperatures and runoff; this treatment might possibly affect the microclimate. The possibility of controlling snow surface temperatures by dusting with various materials has been studied. Removal of algae from cliff surfaces can increase surface erosion.

(1-3) Stumping and Grubbing

Not applicable to this land type.

(1-4) Scraping and Grading

Whether surface alteration techniques, such as scraping and grading with "air-dropped" equipment, will be logistically possible on mountain peaks in the aeolian environment is highly questionable. Surfaces are likely to be snow, ice, rock, and debris with little soil accumulation on steep slopes; some surfaces might be almost vertical. High winds, precipitation, or dense cloud cover might be present. The potential for an avalanche must be considered in some areas. Under these conditions, manual labor might be the only effective resource, as was largely the case in the Greenland "Broken Arrow" incident.

Removal of surface snow and ice can be expected to produce minimal lasting impact. Surface scraping and grading of rock, soil, or debris will tend to accelerate erosive action, the severity of which will depend upon the composition and slope of the surface. If the treatment increases the smoothness of the surface, the potential for a snow avalanche will be increased. Severe alteration of mountain peaks will produce a strong visual or aesthetic impact. Post-treatment measures might be required to reduce the potential for erosion and avalanches. Methods of afforestation and terracing might be considered for these purposes. Depending upon the location of the spill, climatic conditions might permit some degree of afforestation or vegetation above the timberline. Without such measures, recovery, or return to the pre-treatment conditions, could be quite slow. In fact, the net effect of the treatment might be to potentiate the pre-treatment erosive condition. Erosive processes could be accelerated and recovery might never occur.

(1-5) Shallow Plowing

Not applicable to this land type.

(1-6) Deep Plowing

Not applicable to this land type.

(1-7) Soil Cover Less than 25 cm

Application of soil as a coverup type of treatment would not seem to be applicable in the mountain environment because of steep slopes and rapid erosion. Construction of mechanical retaining structures probably would be required. This treatment might be possible behind glacial moraines and in small valleys but contamination of ground water and subsequent flow to streams would appear to render such treatments ineffective. Because of the absence of plant cover growth in the aeolian environment, stabilization of such soil fill would be quite difficult.

(1-8) Soil Cover 25 to 100 cm

Not applicable to this land type.

(2-1) Remove Plow Layer

Removal of soil (if present) will increase exfoliation and erosion of the underlying rock surfaces by making them accessible to temperature extremes and alternation between freezing and thawing. As discussed in Section 5.1.2.3, the daytime sun and shade temperature differential on a mountain peak can exceed 70°F. Snow removal would be expected to produce similar effects. Reference to the particulate adsorptive properties of snow was made earlier in Section 5.1.2.1.

(2-2) Remove Shallow Root Zone

A "root zone" in the sense used in other ecological zones does not exist in the aeolian mountain peak environment. The comments in 2-1 will apply to soil removal to depths usually thought of as the root zone.

(2-3) Remove by Scraping and Grading, Mechanically Stabilize

Removal of soil and rock by scraping and grading, if logistically possible, would probably serve to increase erosive processes. Mechanical stabilization in the sense of soil compaction would probably not be applicable to many sites in this zone. Partial stabilization by methods analogous to those used in trail maintenance may be possible, but their long-term effectiveness is questionable.

(2-4) Remove Plow Layer, Mechanically Stabilize

The mechanisms for thermal fractures of newly exposed surface rock were described earlier in treatment 2-1. For this land type, the feasible mechanical stabilization would be the temporary system of rock-weighted mesh and drilled pins in lead anchors or the use of "rock-bolts." Mechanical stabilization of soil patches by a soil compaction process would be quickly exfoliated by frost heaving and cannot be recommended here. Large areas would be prohibitive to cleanup, and "recovery" in this context would be an indefinable term.

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

This combined treatment is inappropriate for the aeolian mountain peak environment.

(2-6) Remove by Scraping and Grading, Chemically Stabilize

Soil removal followed by chemical stabilization would mitigate some of the consequences of rill and gravitational creep erosion caused by slope steepness until the chemicals break down under ultra light exposure. This breakdown is an indeterminate result and highly dependent upon the cumulative duration of snow and ice cover, and particularly dependent upon slope aspect.

The removal of spilled material by scraping and grading of hard surfaces is subject to those points discussed in treatments 2-1 through 2-3. The effectiveness and consequences of chemical stabilization would depend upon the nature of the site and the properties of the stabilizing material. The use of these methods in areas subject to severe erosive forces is questionable.

(2-7) Remove Plow Layer, Chemically Stabilize

This treatment is inappropriate for the same reasons as treatment 1-4. Chemical stabilization would be less effective than weighted mesh upon those patches where some soil has collected.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

This treatment is not appropriate.

(3-1) Barriers to Exclude People

If the supporting posts can be bolted into rock to support the ice during snow melt, this might be the most realistic temporary procedure while cleanup is carried out. Access barriers might be necessary at greater distances from the primary spill site than for other life zones. Because of the absence of protective vegetative cover, rapid transport of spilled material by water and dissemination by wind can occur immediately after the spill; the spread of contamination to locations remote from the primary site is a definite possibility.

Due to the high danger of spreading of spilled material by wind (in the absence of protective plant cover) and water to sites downslope and/or possibly remote from the primary location, erection of barriers some distance from the spill may be necessary. It may be necessary to restrict access to lakes and streams at lower elevations in the watershed. Valleys at the base of a mountain peak spill site may be subject to wind contamination. Assessment of the dangers of such spread will have to depend upon local evaluation of the site and consideration of the properties of the spilled materials.

(3-2) Exclude Large Animals

The erection of animal access barriers might or might not be necessary, depending upon the site location and altitude. Barriers excluding large animals probably would not be necessary for spills in the aeolian environment since it is far above their normal range. It is unlikely that animals will interfere with the recovery of a treated area, however, they can act as a vector for direct dissemination of radioactive materials.

(3-3) Exclude Large and Small Animals

Small animals in the lower portion of the aeolian zone are generally limited to a few reptiles and insects; these are discussed in the first part of this chapter. Birds, which are occasional visitors to this life zone (also discussed earlier in this report), can be problematical.

(4-1) Asphalt Hard-Surface Stabilization

Outside the scope of work of this study.

(4-2) Concrete Hard-Surface Stabilization

Outside the scope of work of this study.

(5-0) Application of Sewage Sludge

Outside the scope of work of this study.

(6-1) High-Pressure Washing (<3 mm)

Not applicable to this land type due to logistics and recontamination problems.

(6-2) Flooding to 30 cm

Not applicable to this land type.

(7-0) Soil Amendments Added

Outside the scope of work of this study.

5.4.2 Alternative Treatment Techniques

Severe climate is characteristic of this zone with high velocity winds and severely eroding steep slopes at those seasons free water occurs. Snow blasting can redistribute contaminants impacted on high vertical surfaces without interference but horizontal movement can be influenced by diverting melt water with structures, and snow may be managed or directed while in motion.

(8-1) Snowfences and Wind Barriers

These structures can be of temporary benefit in reducing snow accumulation at one small area by holding it in another site. The wind shadow extends leeward 10-15 times the height of permeable barriers. By rule of thumb, a solid wall 0.75 meters high protects the adjacent surface from snowblast and wind erosion to 10 meters downwind and a snowfence 1.2 meters high and of about 50% frontal area casts a wind shadow 12 meters downwind. The most effect is obtained with a rough edge. Wind velocity is least near the ground at 3 to 5 barrier heights on the downwind side of both solid and penetrable barriers. Effectiveness of the barriers and snowfences seems independent of wind speeds, at even high velocity if the barrier is vertical. The principal problem with barriers is that of determining the perpendicular to the direction from which the prevailing high winds scour a given area consistently.

(8-2) Watershed Control Devices Constructed

The usual operations of shaping by clearing (1-2), scraping and grading (1-4, 2-3, 2-6), and revegetation are not viable in this ecosystem as ways of controlling movement of contamination in water. Streams are torrential and mudflows scour deeply in above-freezing weather. The high kinetic energy requires that manual construction methods or small air-freighted equipment of limited capability be used for the diversion structures. These can include stone riprap and diversion dikes and stone gabions across rills and smaller channels. Contoured terraces, stone walls and check dams, and rock outfalls may be feasible as aids in containment when the contaminated area is snow-free. Grade stabilizing structures such as chutes and stone drop spillways can be supplemented by stone levees to modify smaller stream channels and reduce erosive cutting into contaminated "soils" and snowbanks. None of these appear to be effective controls in areas with landslides, avalanches, and even severe snow blast.

(8-3) Snow and Ice Additives

The application of dusts to snow and ice to retard or enhance melting can be useful. Experience with dusting charcoal dusts and lamp black powders over snow and ice showed significant increases in melt rates. That observation, when taken with the observation that deposits of solid particulates are captured while melting occurs, suggests a unique procedure for reducing the volume of snow to be cleaned up. The transportation requirements for dusting material are modest enough to be handled by backpackers, small fixed-wing aircraft, or even avalanche-prevention artillery rifles. Subsequent snow cover cancels the effectiveness of the dusting, but it can be renewed again repeatedly. On the other hand, the potential of reducing melt rates by foamed polyurethane insulation blankets seems not to have been tested experimentally in snowfields as a containment technique. In thoery it would be an effective method for isolating small areas of contamination from heat and winds.

(8-4) Removal of Contaminated Snow and Ice

The logistics of travel in the area seem the most likely source of environmental damage. Melting ice and packed snow requires heat, but given air support, fuel tanks can be supplied and the contamination concentrated by melting the snow and ice carrier. The characteristics of the contamination would control the selection of resin column adsorbers, or using alcohol gels or thixotropic mixtures for containerizing the contamination prior to transportation. Reflective surface solar stills would also be effective as concentrators where sunlight is available because of the high light intensity at high elevations.

5.5 RECOVERY AFTER CLEANUP

The applicability of the term "recovery" to both the biotic and abiotic components of the aeolian zone and mountaintop environment was discussed at the beginning of Section 5.4 on cleanup procedures. The following discussion is subject to the same reservations.

5.5.1 Irreversible Changes

Any treatment that drastically alters the shape or surface of the mountain peaks or slopes or greatly increases the rate of erosion in the barren ecosystem under discussion, can for all practical purposes be considered as irreversible. Destruction of habitats or extremely slow-growing life forms as lichens might be considered to be irreversible from the standpoint of the human lifespan. There is little data on the growth rate of these organisms in the aeolian environment.

5.5.2 Rates of Recovery

There is insufficient data available from cleanup procedures to provide a meaningful discussion of recovery rates of the aeolian mountaintop environment. The abiotic components of the ecosystem might not recover, per se, but will instead establish new rates of erosion which incorporate changes brought about by the cleanup procedures. The degree of the effect will depend largely upon the severity of the severity of the treatment implemented.

With respect to the biotic components of the aeolian system, it can be inferred from observations on the establishment of lichens in areas uncovered from permanent snow that recovery for these organisms will be extremely slow. Algae, if removed from cliff surfaces, or with snowpack, probably will be able to become reestablished in a relatively short period of time. If food sources for zoological components of the aeolian environment are removed from the spill area, it can be expected that their reestablishment (dependent upon buildup of concentrations of organic materials of aeolian derivation) will be slow in some cases and rapid in others. Lizards that depend upon windblown insects might be able to become reestablished in a treated area within a few generations; aeolian insects, dependent upon collected organic materials in cracks and crevices, might require many years to become reestablished. There is insufficient data to speculate upon the recovery rate of snowworm populations that might be depleted or eliminated with the removal of contaminated snow during the cleanup process.

5.5.3 Successional Stages

The "recovery" events that occur within arbitrary "successional stages" will vary greatly depending upon the location, situation, season of the spill, and the treatment applied. The discussion here will apply only to the biotic phase of the environment. It is emphasized that there is little data or precedence for these estimates, and that they are essentially educated guesses. Deterioration can be expected for the abiotic phase of the system; the rate will depend upon the location of the spill and the nature of the treatment. Since lichens are the most visible biotic component of the aeolian mountain environment, their recovery will be assumed to essentially signal the "recovery" of the biotic component.

5.5.3.1 First Year--

In the first year, regeneration of disturbed, removed, or destroyed microbial forms, including algae on cliffs and snow fields, probably will be well underway. It is assumed that these organisms are reasonably well adapted to the environment and enjoy relatively short generation times. Higher forms of animal life that are mobile and can subsist on windblown insects might have begun to reinvade the treated area.

5.5.3.2 Fifth Year--

By the end of the fifth year, the microbial lifeforms will be well established and the higher animal life forms probably will have recolonized the niches able to provide sufficient food. If algal forms were removed from cliff faces during the treatment, they also probably will be reestablished, although the thickness of their "mat" probably will not be fully developed.

5.5.3.3 Tenth Year--

By the end of the tenth year, there should be sufficient accumulation of windblown organic debris in cracks and crevices to permit survival of small populations of those species of spiders, mites, etc., that utilize this nutritional source. Algal mats should be well developed on cliff faces (if there is a favorable habitat in the cleanup area). Vertebrate populations (lizards) probably will have attained equilibrium by this time. With the exception of the slow-developing lichens, the biological climax populations of the aeolian life zone should be well on the way to recovery in the treatment zone, assuming that the treatment did not leave residual chemicals or mechanical structures. By the tenth year, small lichen colonies may be reestablished over the treatment area, if lichen growth preexisted the treatment and lichen growth was completely removed during the treatment.

Speculation beyond this time period seems meaningless because, in the absence of protective vegetation sufficient to provide stable microhabitats, changes in climatic patterns might occur that are great enough in magnitude to alter the environment and its biota. If lichen growth preexisted the treatment, it should be reasonably recovered by the 100th (or perhaps by the 50th) year, subject to the factors discussed earlier in this section.

5.6 QUANTITATIVE ASSESSMENT OF CLEANUP IMPACTS

Environmental forces are asserted differentially in the aeolian mountain from "normal" zones, and the effects of recovery from cleanup are evaluated differently. Lack of soil cover throughout and the absence of flowering plants lends a restricted meaning to recovery. In the following discussion, recovery means that the rate of erosion of surface features has been slowed to the rate of loss that existed before contamination. The eroding surfaces may be snow fields, snow banks, aeolian mineral drifts from rock, ice features, rock faces, or other surfaces, including patches of frozen and unfrozen "soils." Life forms that exist year 'round are sophisticated, such as lichens and snow worms or primitive bacteria and algae. Transient populations of insects attract scavenger birds temporarily into the aeolian peaks.

Wind-drifted mineral deposits collected around rocks and ice features and on and in snowbanks form the sites for "soil" accumulation. Soils and vegetation in the normal sense are absent. In their place are patches of rock-weathering products combined with wind-drifted solids to form mineral pockets of a few square meters in area. Continuous areas of soil patch as large as 0.01 km^2 are rare, and for discussion of larger areas to 0.1 and 10 km^2 of cleanup, the effects must be imagined as imposed upon an increasing number of patches scattered around one or several mountain peaks. Consequently, the impacts from the effects of cleanup are those registered upon small mineral patches whether it is one patch or large numbers of "soil" patches among bare rock and snow and ice fields.

The majority of the cleanup treatments evaluated in the report are inappropriate in this zone, especially those which involve the redistribution of soils (1-3, 1-6, 1-7, and especially 1-8).

Use of stabilizers is judged ineffective without there being precedent to judge from. This area is considered significantly different from spoil banks at lower elevations. At those sites particle size ranges exist, and the surface dries off after precipitation. In the mountain, piles of aeolian debris are intermittantly soaked or ice sheathed where chemical stabilizers are unlikely to stick, and it is not likely that sublimation is an effective drying agent. Single-grain coarser material is filled with rock fragments or covered with rock too large to hold in place with sprayed solution. No effective use can be projected for treatments 1-1, and 2-3 through 2-8. Thermal problems with chemical stabilizers are extreme at these heights.

Five groups of time to recover are shown in Table 5-2. These rank as groups from most destructive but acceptable at some sites (1-4, 2-1, and 2-2); through less destructive, if considered to apply only to lichens (1-2 and 1-5); then, potentially destructive, but not required to be (8-2). These are the cleanup techniques that can take a century or more to repair.

Impacts only fractionally as retrogressive are imposed by Treatments 8-1 and 8-3 and mainly on solid precipitation. Removal of contaminated ice or snow is ranked in this same time span. The non-impact cleanups are the barriers (3-1, 3-2, and 3-3).

In Table 5-2 the operations of clear cutting (1-2) and shallow plowing (1-5) are restricted to scraping lichens from their support. In this snow-blasted and windy zone, ten years may pass before recolonization occurs, and one or several centuries are likely to pass before a full-standing crop is established again. This is a drastic cleanup and has the longest recovery time of the likely treatments on vegetated sites. Similar effects and recovery are attributed to treatment 1-5 when applied to lichens.

The most drastic cleanup after-effects upon the environment derive from removal of the aeolian "soils" in treatments 1-4, 2-1, and 2-2. Replacement with additional aeolian debris to an equivalent depth is postulated to take one to several centuries. If treatment 8-2 were to be constructed of these

Table 5-2. Estimates of the years to reach recovery after various cleanup treatments.

Treatment	Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	---	---	---	---	Insufficient data to estimate.
1-1 Chemical Stabilization	NA	NA	NA	NA	
1-2 Remove Vegetation by Clear Cutting	30-100	30-100	30-100	30-100	Applies to lichens only.
1-3 Remove Stumps and Grub Roots	NA	NA	NA	NA	
1-4 Surface Scraping and Grading (<5 cm)	100+	100+	100+	100+	Soil replaced only by wind & sedimentation action.
1-5 Shallow Plowing (<10 cm)	30-100	30-100	30-100	30-100	Lichens only.
1-6 Deep Plowing (10 to 40 cm)	NA	NA	NA	NA	
1-7 Soil Cover (<25 cm)	NA	NA	NA	NA	
1-8 Soil Burial (25 to 100 cm)	NA	NA	NA	NA	
2-1 Remove Plow Layer Soil (10 cm)	100+	100+	100+	100+	Soil replaced only by wind & sedimentation action.
2-2 Remove Shallow Root Zone Soil (<40 cm)	100+	100+	100+	100+	Soil replaced only by wind & sedimentation action.
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	NA	NA	NA	NA	
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	NA	NA	NA	NA	
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	NA	NA	NA	NA	
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	NA	NA	NA	NA	
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	NA	NA	NA	NA	
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	NA	NA	NA	NA	
3-1 Barriers to Exclude People	0-1	0-1	0-1	0-1	No significant effect.
3-2 Barriers to Exclude Large Animals	0-1	0-1	0-1	0-1	No significant effect.
3-3 Barriers to Exclude Large and Small Animals	0-1	0-1	0-1	0-1	No significant effect.
4-1 Asphalt Hard-Surface Stabilization	*	*	*	*	
4-2 Concrete Hard-Surface Stabilization	*	*	*	*	
5-0 Sewage Sludge Application	*	*	*	*	
6-1 Washing (<3 mm)	0-5	0-5	NA	NA	
6-2 Flooding (3 to 30 cm)	*	*	*	*	
7-0 Soil Amendments Added	*	*	*	*	
8-1 Snow Fences and Wind Barriers	0-10	0-10	0-10	0-10	Minimum damage.
8-2 Watershed Control Devices Constructed	1-100	1-100	1-100	1-100	Variable impact from specific structures placed.
8-3 Snow and Ice Melt Additions	0-10	0-10	0-10	0-10	Relatively minor impact but additive specific.
8-4 Removal of Contaminated Snow and Ice	0-5	0-5	0-5	0-5	Site dependent impact depends on removal logistics.

*Outside scope of work.
NA - not appropriate in this land type.

"soil" materials it would be rated equally damaging. The recommended construction materials are rock fragments for the structures proposed to divert snow melt.

Stone filled diversions created from tatus (8-2) are expected to be restored in a few years by natural rock-falls. Except for the potential for misuse of soils, this technique would be rated as little impact, as are Treatments 8-1 and 8-3. Installation of fences (8-1) to create drifts and melting of snow and ice (8-3) are rated benign as is removal of contaminated snow and ice (8-4). High pressure hosing down with water (6-1) has little impact if the logistics of obtaining the required water is met by an environmentally benign way.

The procedures judged least destructive are shown in Table 5-2 as barriers, mainly barriers to keep people out (3-1) and a few transient animals that may pass through (3-2, 3-3). Damage during barrier installation is presumed minimized and remedied by solid precipitation cover in a few months.

The effect of increasing the area of cleanup can only be visualized as including additional numbers of discrete and overall cleanup sites because of the terrain being limited in area. The impacts and the times to recover are area independent due to frequent transitions from ice to rock to snow cover.

5.7 CONCLUSIONS

Because of the complete lack of vegetative cover and the extreme severity of physiographic and climatic factors in the aeolian mountain peak environment, most of the conventional cleanup procedures considered for other terrestrial life zones and environments appear to be either inapplicable or logistically impracticable, and probably would be minimally effective. For these reasons, and the fact that precedents for perturbations of this environment and recovery therefrom are extremely rare in the literature, accurate quantitative estimation of the impacts of these treatments would be difficult. It might appear that alternative treatments that are applicable to the aeolian mountain peak situation should be devised as a separate study, and their impacts then considered. Possible alternative avenues of approach have been mentioned in this report. With respect to "conventional" cleanup procedures, those involving surface alteration and hard-surface stabilization appear to have the most lasting impacts. The severity of impact and the amount of time required for "recovery" varys depending upon the location and precise situation of the spill and the exact nature of the treatment imposed.

It is suggested that alternative techniques for immediate containment and subsequent cleanup which are suited to the aeolian mountain peak situation be devised. These techniques would be more effective and less detrimental than those methods devised for other environments.

The preferred treatments are those involving barriers (3-1, 3-2, 3-3) and removing contaminated snow or ice (8-4). The least suitable treatments are those which strip the lichens from surfaces, and defined this way are Treatments 1-2 and 1-5, although they are not physically the most destructive.

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CHAPTER 6

TUNDRA

6.1 OVERVIEW

Tundra, which in Russian-Finnish usage referred to the treeless zone of northern Eurasia, especially Finland, was subsequently applied to its counterpart in the Arctic and Alpine North America. The Soil Conservation Society of America defines tundra as "the treeless land in arctic and alpine regions; varying from bare area to various types of vegetation consisting of grasses, sedges, forbs, dwarf shrubs, mosses and lichens." It is generally considered that the tundra vegetational life-form represents the integrated effect of primary climatic parameters. From a practical point of view, tundra should be defined by combinations of physiognomy and environment.[24] In this definition the tundras are the grassless arctic plains, the vegetation of which may form varied and often complex patterns of dominance by dwarf-shrubs, sedges and grasses, mosses, and lichens. The tundras of North America and Eurasia are quite similar; their principal herbivorous mammals include the musk ox, caribou, arctic hare, and lemming. Longspurs, plovers, snow bunting, and horned larks are characteristic birds; reptiles and amphibians are few or absent, as in alpine grasslands. In many tundras the deeper layers of soil are permanently frozen, and only the surface soil is thawed and becomes biologically active during the summer. The semi-arid areas of the Arctic are generally considered as part of the tundra.

Dagon[7] stated that the variety of definitions and the resultant misunderstanding accompanying the application of the term tundra have been far too numerous. He lists numerous definitions for the term and points out that there is a great deal of ambiguousness associated with the use of the word tundra. For the purpose of this report, the term tundra defined on the basis of its physiognomy and environment is more appropriate.

6.1.1 Geographical Distribution

Tundra lies between the northern limit of trees and the area of perpetual ice and snow in the far north, or above timber line in high mountains. In North America, it forms a broad band completely across the continent, and it also occupies the narrow low coastal area around most of the periphery of Greenland. It occurs on mountains as far south as Mexico if their elevation is sufficient to produce a timber line. Thus it is limited in its northern or upward extent by ice and bounded on the southern or lower margin by boreal or subalpine conifer forest. The tundra is essentially an arctic grassland. It is the cold polar area beyond the treeline in the northern circumpolar lands of North America and Eurasia. The tundra vegetation and environment continues southward along mountain alignments in western North America and Siberia. The term tundra is further subdivided into Arctic and alpine. Alpine and Arctic tundra are discussed in detail in the vegetation section (6.1.3) of this chapter.

6.1.2 Environment

Low temperatures and a short growing season (about 60 days) are the main characteristics of tundra environment. The ground remains frozen except for the upper few inches during the growing season. The dominant factors which shape the tundra environment[14] are: the character of the solar energy input, the nature of the immediate and adjacent surfaces, weather systems, and topography. The annual and daily cycling of solar energy received on a unit surface in the arctic tundra is quite different from that experienced at lower latitudes. In general, tundra summer is limited to the three months of June, July, and August; winter occupies the remainder of the year. Daily air temperatures are generally below 10°C in summer but may rise occasionally to 20°C during brief sunny spells. The mean daily range of temperature in summer is about 6°C. The coldest months are December through April; the mean daily temperature in tundra areas in February is about -30°C and the mean daily range varies from about 10 degrees in continental areas to about 6 degrees elsewhere. Extreme low temperatures of about -50°C occur in the exposed tundra. Topography and vegetative cover are probably important factors in the temperature regimes of tundra environments.

The tundra is often termed a "polar desert." Annual precipitation in this area is indeed light. However, thawing of the active layer each summer causes vast tracts of wet lands. By and large the annual rainfall is equal to the water equivalent of snowfall. Normally there is adequate precipitation for vegetative growth; deficiencies in moisture supply become critical only briefly during the occasional summer droughts. Droughts have been sufficiently severe to permit serious tundra fires to occur. Low evapotranspiration rates and the presence of permafrost result in a large percentage of the precipitation running off into the tundra's poorly developed streams and stagnant ponds. It is difficult to overemphasize the importance of the snow cover on the tundra during the eight to ten months of the year. Snow is essential to the survival of many plants and animals. In addition to being a source of water, snow acts as a protective blanket to many plants and animals.

Wind plays a dominant role in the tundra. Strong winds are usually the most critical.

Both plant and animal life exist precariously, mainly by taking refuge in a particular microclimate environment and thereby escaping the rigors of general climate. The microclimatic environment is in a delicate state of balance, and alteration of this balance either naturally, or unnaturally, such as through vegetative modification, may have serious consequences. For example, the alteration of albedo can upset the energy balance at the soil surface and result in thermokarst conditions. The removal of tall vegetation will result in increased winds and shallower snow cover which may also significantly change the thermal regime near and in the ground.

6.1.3 Vegetation

Tundra vegetation is low, dwarfed, and often matlike, and includes a high proportion of grasses and sedges. Even the woody plants, including the willows and birches, are usually prostrate. The herbs are mostly perennial and of a rosette type, producing relatively large flowers, often with conspicuous colors. Mosses and lichens may grow anywhere and in favorable habitats form a thick carpet with the low herbs. The number of species is small compared with floras of temperate climates; and, even within the tundra, the number decreases northward. Most of the genera and many of the species are to be found throughout the Northern Hemisphere wherever tundra occurs.

The uniformity of the flora is undoubtedly related to the peculiarities of environment. The growing season is short and its temperatures are relatively low. Permafrost in the ground and its depth of thawing in summer is of great importance as is the extreme instability of soil, related to the frost action.[19] Light is continuous throughout the growing season in the arctic tundra, and is intense and high in the ultraviolet rays in alpine tundra. Local marked differences in vegetation are commonly related to minor variations in topography and differences they produce in drainage and retention of snow.

The tundra ecosystem can be divided into (1) Arctic Tundra, and (2) Alpine Tundra.

6.1.3.1 Arctic Tundra--

The circum-artic tundra can be regarded as comprising a simple formation-type composed of Eurasian and North American formations. Even within the same formation, however, in spite of superficial similarities, considerable contrasts are evident in both life-form and general appearance. Although flowering herbaceous plants, particularly grasses and sedges, are almost universal throughout all communities, dwarf shrubs, mosses and lichens compete successfully in most places. Furthermore, there is a great contrast between the almost closed-cover tundra communities near the forest margins and the scattered, sparse communities on almost bare ground in the most inhospitable parts of north Greenland and Spitzbergen. It is clear also that not all the extensive tundra communities are to be regarded as true climatic climax.

In the climatically more favored areas of the tundra, the true climatic climax communities are probably those in which grasses and sedges are dominant with a substantial understory of lichens and mosses. Communities of this nature are found on undulating areas with a considerable range of slope, aspect and lithology. The dominants in the American formation are various species of sedge (Carex spp.), cotton grass (Eriophorum spp.), and woodrush (Luzula spp.), along with species of many genera of grasses such as the bents (Agrostis spp.), foxtail grasses (Alopecurus spp.), fescues (Festuca spp.), and timothy (Phleum spp.) which are also of common occurrence in middle latitudes. The commonest associated lichens belong to the genera Stereocaulon, Alectoria, Cetraria, and Cladonia, while mosses of the genus Polytrichum are most frequently encountered. Along with these are a great variety of plants with showy flowers belonging to genera which are also distributed throughout the woodlands and meadows of middle latitudes such as the anemones (Anemone spp.), marsh marigolds (Caltha spp.), buttercups (Ranunculus spp.), avens (Beum spp.), cinquefoils (Potentilla spp.), campions (Lychnis spp.), catchflies (Silene spp.), and primroses (Primula spp.). These are accompanied by flowers which are more typically associated with high latitudes and high altitudes such as the mountain avens (Dryas spp.), saxifrages (Saxifraga spp.), and gentians (Gentiana spp.). A varied cover of predominantly herbaceous vegetation thus forms an almost complete turf over the ground.

Over very large areas, however, the grasses and sedges are much less important and dominance is assumed by foliose lichens and mosses, particularly the former. This cover of cryptogams, if ungrazed, may be anything from four to ten inches high and, in the more southern parts of the tundra, may be almost continuous. Further north communities similar to the two already described are much more discontinuous and a great deal of bare ground is found between individual plants or plant aggregates. This type of vegetation has been most vividly described in the Taimyr Peninsula by Middendorf. Here, in many places, the ground is only about half covered by plants, permafrost is not more than three inches beneath the surface in many places, and a varied patchwork of communities is found. In places mosses (Polytrichum spp.) dominate; elsewhere sedges or lichens (Cladonia spp.). Throughout all these communities, however, there is an admixture of flowering plants, creeping shrubs such as the dwarf willow (Salix lapponum) and xerophytic, heath-like shrubs such as the crowberry (Empetrum nigrum). Even at the height of summer, when many species are in flower, these communities give the landscape a drab or yellowish aspect. This is partly due to the colors of the mosses and lichens, but partly to the fact that many of the grasses and other flowering plants, as an adaptation to reduce transpiration, retain the dead remains of last year's growth. Ultimately, around the very fringes of ice caps and on some exposed sea coasts, the vegetation dwindles and only an occasional tussock of sedge or cushion-shaped plant is to be found.

Dwarf shrubs occur sporadically throughout the communities already described but locally shrubs become dominant. Usually, however, the shrubs, which are subordinate elements in predominantly herbaceous communities, belong to different species from those which form arctic heath and arctic scrub communities. In arctic heath the species are low growing, the Canadian communities being dominated by small shrubs such as the arctic bell-heather (*Cassiope tetragona*), crowberry (*Empetrum nigrum*), and alpine bearberry (*Arctostaphylos alpina*). In arctic scrub, on the other hand, quite a busy growth is attained which may reach a height of several feet. It is dominated by broad-leaved shrubs such as the narrow-leaved Labrador tea (*Ledum palustre*), Lapland rose-bay (*Rhododendron lapponicum*), alder (*Alnus sinuata*), scrub birch (*Betula glandulosa*), and numerous species of willow (*Salix* spp.). Many communities are found containing both these types of shrub, however.

Usually the arctic shrub communities are found on sheltered slopes, particularly where the soil thaws unusually deeply in summer and where it is rich and moist. It seems probable that they constitute a zone of ecotone between the more typical tundra communities on the interfluves and the outliers of the forest on the lowest slopes. There is some evidence that, where trees are nearby, invasion takes place sporadically in a series of favorable years only to be rebuffed in a subsequent unfavorable period.

Finally, there is another suite of communities, covering extensive areas in the tundra, which cannot be regarded as climatic climax; these are the tundra bogs and moors. They are very similar in appearance and species-content to the bogs or "muskegs" which occupy ill-drained localities within the general area of the boreal forest. Very often in both Europe and America, they are dominated by cotton grass (*Eriophorum vaginatum*) along with many other species of sedge and some grasses. Usually also various species of moss, particularly bog moss (*Sphagnum* spp.), compose a sub-dominant understory. The surface of these bogs is usually "tussocky" and the tussocks of cotton grass and moss are frequently invaded by dwarf willows. Indeed, at an advanced stage of development, when the peat has achieved considerable thickness, the vegetation may become quite luxuriant, similar in many ways to that of the better-drained arctic heaths. These "heath moors," as they have been called, ensure a copious supply of available moisture throughout the growing season and, at the same time, thaw out to a sufficient depth to accommodate the rooting systems of shrubs. Apart from the heathy shrubs, some broad-leaved, deciduous shrubs also invade this kind of surface. In Canada, for instance, several species of birch (*Betula*) and many of willow (*Salix*) are of frequent occurrence. It seems likely that soil conditions here would be quite suitable for those species of tree which regularly invade drying-out muskegs within the boreal forest areas — species like the black spruce (Picea mariana) and the Canadian larch or tamarack (Larix laricina). Indeed, if these species of tree were able to advance uninterruptedly, along a solid front, across bogs in the southern parts of the Canadian tundra, they would probably demonstrate their ability to survive the climatic rigors there. Individual tree seeds which have been carried by the wind have been observed to germinate here quite satisfactorily but have subsequently been incapable of surviving the desiccating blizzards of winter. Isolated saplings cannot survive but if they had the partial shelter of nearby parent trees, they would probably be able to do so; the forest would thus encroach gradually. This cannot take place, however, since the deep peat areas are separated from the forest edge by less favorable types of terrain.

The intense physiological drought of the winter months should be stressed as a limiting factor in the tundra far more than mere low temperatures. If the air always remained still, many of the northern trees could probably withstand even lower temperatures than they do. Strong winds, even at very low temperatures, are able to abstract water quite quickly from living plant tissues; if this proceeds beyond a critical point, death ensues, since no replacements are obtainable from the completely frozen soil. The plants of the tundra minimize the danger of this in several distinct ways. On the most exposed areas, all are very low-growing; many die down completely in winter and survive as underground rhizomes, root stocks, corms and bulbs. Those herbaceous plants which do maintain organs above ground level in winter do so in the form of very tight-packed rosettes or cushions; many species of saxifrage do this very successfully. As a group, the lichens are noted for their ability to survive in an almost desiccated state for protracted periods. It is understandable therefore that they should form such an important element in the vegetation of many of the bleakest and baldest arctic interfluves. The arctic shrubs are also low-growing except in the most sheltered valleys. They have adopted different devices to prevent over-rapid transpiration. Many of the broad-leaved ones are deciduous (Salix, Alnus, Betula) while the heaths all have the characteristic small leaves with rolled-back margins.

The shortness of the growing season also imposes great restrictions on plant growth. It is mainly because of this factor that the flowering herbs of the tundra fall into two classes; there are those which flower at the beginning of the growing season and those which flower towards the end of it. The early-flowering species are typically plants with substantial underground food-storage organs; they use the stored energy from the preceding year to flower and produce seed and then utilize the remainder of the growing season to build up food for the following year. The late-flowering species use the first part of the season to build up a store of energy and then use most of it in producing seed; they then pass the winter as inconspicuous underground organs or, if annuals, survive merely as seeds.

The factors of winter frost, winter winds, short growing season and permafrost are responsible, collectively or separately, for precluding trees from the tundra. Because of contrasts in relief and aspect the relative importance of these different factors varies greatly and an evaluation of the exact reasons for the absence of trees in a particular place is usually obscure. However, the complex inter-digitation of the southern edge of the tundra with the northern edge of the forest indicates that, generally speaking, wind force along with shallowness of unfrozen soil are the operative factors in the southern parts of the tundra. Here, forests occupy the valleys while the interfluves are tundra. Wind force is obviously important on these interfluves but, whether forest would extend further up the slopes if the depth of the thawed layer in summer were deeper is not clear. The existence of permafrost, as such, does not preclude forest since vast areas of the northernmost parts of the boreal forest are underlain by it both in Siberia and Canada; northern species such as the Dahurian larch (Larix dahurica) and Siberian dwarf-pine (Pinus pumila) are adapted to this soil condition in that they develop a root system which is entirely spreading with no tap root whatsoever. In the northern archipelago of Canada and the arctic peninsulas and islands of the U.S.S.R., as well as in the Spitzbergen and the north of Greenland, it appears probable that trees cannot possibly regenerate regardless of wind and soil depth. Though increase in the length of the season with continuous daylight does, to a certain extent, compensate for increased latitude, it is doubtful if the growing season here is sufficiently long for trees. Even if trees could survive the winter, it is very doubtful if they would be able to flower and produce seed. In these fringing areas, so near to perennial ice, there is no recognizable frost-free season. Everywhere in the tundra the mean length of the frost-free season is less than fifty days but here, in spite of continuous daylight, air frosts occur frequently in all the summer months. Returning to the southern fringes of the tundra, however, it is doubtful whether the length of the frost-free season has any bearing on the position of the limits of the forest. Probably the length of the frost-free season is sufficient here to permit forest regeneration but wind speed in winter and extreme shallowness of soil in summer prevent the spread of trees.

Fluctuations in the position of the northern edge of the boreal forest have occurred during the past few millennia. Locally, in European Russia, a distinctive fringing zone of "tundra moor" has been described. Here, hummocks of bog moss (Sphagnum spp.) peat, each several yards in diameter, with narrow, marshy channels between them, cover the landscape. The mosses on the hummocks are often still growing but the cores of the hummocks are permanently frozen. This permanently frozen peat contains the stumps of both birches and conifers, many of which are in position of growth. Clearly these areas were forested not so very long ago but the reason for forest recession is not altogether clear. Possibly a deterioration in climate was responsible; possibly, the activities of reindeer herders along the former forest margins caused the saplings to be grazed off and thus prevented regeneration; possibly both climatic change and human activity played some part in the changes that occurred.

Although the flora of the tundra is fairly well known, its communities and their successional relationships have not been sufficiently studied. In contrast with temperate vegetation, many species may occur in any type of habitat, and several that appear to be climax may also be pioneers in the newest of habitats. Even climax is not agreed upon, possibly because observations have been made in widely separated areas. Variations do exist, as has been shown for eastern Canada. It is also possible that the climax criteria used for temperate climates are not always applicable in the arctic. Interpreted in terms of Greenland vegetation, Cassiope heath appears to be climax, and a Sedge-Dryas dominated community, of equal extent but on drier sites, is preclimax. Two subclimaxes are frequent. Any habitat with sufficient moisture, whether it be pond margin, seepage area, or boggy ground, eventually is covered with a thick moss mat supporting several herbs, of which cotton grass (Eriophorum spp.) is most conspicuous. Xerarch succession on rock exposures eventually results in a lichen-moss mat, which may continue almost indefinitely.

Important climax dominants are Cassiope tetragona, one or more species of Vaccinium, Archtostaphyloas alpina, Empetrum nigrum, Andromeda polifolia, Ledum palustre, Phododendron lapponicum, and species of Betula and Salix. These and other species occur in varying combinations and degrees of importance.

Practically all habitats support some of the many species of Carex, of which the commonest include C. capillaris, C. nardina, and C. rupestris. The preclimax sedge community invariably includes Elyna bellardi in abundance. Some grow mats, some are in clumps, but all are dwarfed. The same can be said for the grasses, which, although relatively abundant and widespread, are restricted to a few genera, of which Festuca and Poa are especially well represented. Many of the conspicuous herbs previously mentioned are included in the numerous species of one of the following genera: Saxifraga, Potentilla, Ranunculus, Draba, Cerastium, Silene, Lychnis, Stellaria, and Pedicularis. Conspicuous and widespread species typical of tundra are Oxyria digyna, Papaver spp., Dryas octopetala, and Epilobium latifolium.

6.1.3.2 Alpine Tundra--

Mountains high enough to have timber line support tundra, whose upward extent is limited by the snow line. In the east, as a consequence, tundra is found only on a few high peaks in New England. Farther south, the Appalachians are not of sufficient height to support tundra. That on Mt. Washington is representative of the type and is essentially similar to the not far distant arctic vegetation.

Alpine tundra in the western mountains mostly lies far to the south of the arctic and, consequently, is found at high altitudes only. In the Canadian mountains, it is found as low as 6,000 feet, but southward its lowest elevation steadily increases some 360 feet per degree of latitude to 30° north latitude, and then declines very gradually to the equator. In the central Rocky Mountains, tundra is well developed between 11,000 and 14,000 feet. In the Sierra Nevada, where the snow line is lower, tundra lies mostly between 10,500 and 13,000 feet. In general, it is lower on coastal than interior ranges and on the wetter sides of mountains.

When climate changed and terminated the glacial period, vegetation similar to modern tundra must have followed the ice as it receded northward. This left only these high peaks and ridges where tundra could survive as relicts. The relict vegetation obviously belongs to the Tundra Formation because of the growth form and the duplication of characteristic genera as well as many species. The greater importance of grasses and the presence of numerous endemics in the western mountains suggest that these alpine tundras might be classed as associations of the Tundra Formation.

Webber[23] compared the composition and production of the vegetation at Point Barrow (Alaska) and Niwot Ridge (Colorado). The apline tundra vegetation on Niwot Ridge is twice as productive as arctic tundra (Point Barrow) but only because of higher incoming solar radiation (Table 6-1).

6.1.4 Animal Life

The animal life in the tundra biome consists of caribou, musk ox, arctic hare, lemming, longspurs, plovers, snow bunting, and horned larks. There are very few, if any, reptiles and amphibians in the tundra environment. Though vertebrate animals inhabiting arctic and alpine tundra environments are faced with many similar environmental problems, such as low temperatures and scarce cover, important differences between arctic and alpine environments exist in day-length and solar radiation patterns, topography and moisture, and other physical factors of the environment. These differences in environment are reflected in the distribution of animal life in the arctic and alpine tundra. The differences occurring between arctic and alpine faunas are due not only to real differences in the habitats available as a result of physical environmental differences, but also to the much patchier "island" distribution of alpine habitats in contrast to those of the more continuous circumpolar arctic.

6.1.5 Soils

Low temperatures and, in most places, the presence of an impermeable perennially frozen substratum, are the dominant factors affecting the development of soils of the arctic and alpine tundra. The cold environment modifies soil-forming processes to such an extent that it overshadows, and may even completely obliterate, the effects of relief and time on soil characteristics. Tundra soils are wet nearly continuously during the thaw period. In general, the tundra soils can be divided into two groups: (1) poorly drained soils that are usually saturated, and (2) well drained soils.

Table 6-1. Comparison of arctic and alpine environments and vegetation.

Component	Arctic tundra	Alpine tundra
Latitude	71°N	40°N
Altitude (meters)	7	3749
Average July solar radiation (cal/cm^2/min)	0.30	0.56
Maximum photoperiod	84 days	15 hours
Maximum air temperature (°C)	3.9	8.5
Maximum soil temperature (°C)	2.5	13.3
Annual mean precipitation (mm)	107	1021
Permafrost	Universal	Sporadic
Average length of growing period (days)	55	90
Number of common vascular plants	40	100
Average areal vascular production (grams/m^2/yr)	100	200
Average ratio of above- to below-ground biomass	1:8	1:12
Average areal net photosynthetic efficiency (percent)	0.5	0.5

Poorly drained mineral soils of the tundra all have essentially the same sequence of horizons. They consist, typically, of a mat of organic materials at the surface; a grey, greyish brown, or bluish mineral layer which may be mottled in whole or in part with colors ranging from olive or olive brown to reddish brown and which may contain patches or streaks of organic matter; and a grey perennially frozen layer which may have patches of organic matter in its upper part. The description in Table 6-2 of a soil in northwestern Alaska[10] is representative. (Color and Munsell color notations are for moist conditions unless otherwise noted. Depths are measured up and down from the surface of the mineral soil.)

Well drained soils occur throughout tundra areas, but are of relatively small total extent except in arid regions near the northern limits of vegetation. South of those regions they occur almost exclusively in stony, gravelly, or coarse sandy materials on steep slopes, high narrow ridges, escarpment edges, stabilized dunes and beach ridges, and elevated portions of flood plains. The combination of coarse-grained materials and exceptionally good surface drainage is, with rare exceptions, an essential condition for their existence. Either bedrock or dry permafrost underlies these soils; where they are developed in thick unconsolidated materials, solid permafrost may occur at greater depths.

The well drained soils differ from most soils of the tundra in that excess moisture is able to escape. As a result, oxidizing rather than reducing processes are dominant, and soluble products of weathering are redistributed or removed from the soil. The rate of weathering, decomposition or organic materials, and movement of materials (that is, the intensity of soil development) depend on temperature and the amount of moisture available. In the cold and relatively arid arctic environment, these processes go on at a much slower rate than in forested areas to the south. As a consequence, the soils that are formed may have the same sequence of horizons as in comparable well drained soils of taiga areas, but have much thinner horizons. In nearly all cases, physical and chemical properties of the soils reflect those of the parent materials.

The well drained soils vary in the kinds of horizons that develop, and in the thickness and degree of development of the horizons. The soil described in Table 6-3, from southwestern Alaska,[18] is representative of the most extensive of these soils. Colors are for moist conditions.

Table 6-2. Representative poorly drained tundra soil.

Horizon	Depth (cm)	Color	Consistency
O11	18-8	Black (7.5YR2/1, wet) to dark brown (10YR4/3, squeezed)	Partially disintegrated, finely fibrous peat.
O12	8-0	Very dark grey (10YR3/1, wet) to dark brown (10YR3/3, squeezed)	Partially disintegrated, finely fibrous peat, with inclusions of olive yellow and olive brown silty material.
B21g	0-3	Dark grey (N 3/) silt loam, with common large distinct olive brown (2.5Y 4/4), light olive brown (2.5Y 5/4), and grey (N 5/) mottling or staining	Nonsticky and nonplastic; few roots.
B22g	3-23	Dark grey (N 4/-3/) silt loam; massive, with tendency toward platiness	Nonsticky and nonplastic; some small pebbles; abrupt smooth lower boundary. The lower 3 cm of this horizon has erratic streaks of fine soft concretionary material intermixed with partially disintegrated organic material.
C1f	23-28	Frozen very dark grey (N 3/) silt loam	Includes partially disintegrated, finely fibrous, very dark greyish brown organic material; some small rock fragments.
C2f	28-46	Frozen dark grey (N 4/) silt loam	Includes dark brown (7.5YR 3/4) partially disintegrated, finely fibrous organic material; ice constitutes about 75 percent of volume.

Table 6-3. Representative well drained tundra soil.

Horizon	Depth	Color	Consistency
01	5-2		Mat of loose litter, roots of shrubs and grasses, and partially decayed organic materials.
02	2-0	Dark reddish brown (5YR 2/2)	Well decomposed organic matter; many roots; strongly acid; abrupt smooth lower boundary.
A11	0-8	Dark brown (7.5YR 3/2)	Very gravelly silt loam; weak very fine granular structure; very friable, smeary when rubbed; many roots; very strongly acid; abrupt wavy boundary.
A12	8-15	Dark brown (7.5YR 3/2)	Very gravelly silt loam; weak very fine granular structure; friable; roots common; very strongly acid; clear wavy boundary.
B	15-30	Brown (10YR 4/3)	Very gravelly silt loam; weak very thin platy structure; friable; roots common; many fine tubular pores; dark brown (7.5YR 3/2) krotovinas up to 8 cm in diameter; few roots; very strongly acid; gradual boundary.
C	30-71	Brown (10YR 5/3)	Very gravelly silt loam; weak thin and medium platy structure, breaking to very fine angular blocks; friable; no roots below 50 cm; strongly acid.

The principal horizons in this soil are the dark upper horizon and the yellower subsoil horizon, which grades into the shaly parent material. The soil is acid and low in exchangeable bases throughout. Chemical analyses indicate the A12 horizon is slightly higher in free iron than both the A11 horizon above it and the B horizon below it. A similar distribution of iron has been noted in other soils of this kind,[9,5] indicating that there is a tendency in these soils toward the development of an iron-rich subsurface horizon. The process of podsolization, in which iron, aluminum, and organic carbon are moved in solution from the upper mineral horizon and reprecipitated in a lower horizon, is common in soils of cool, moist, forested regions. In a few places in tundra regions just north of the treeline where large quantities of water move through coarse-grained soils, as in micro-depressions in uplands or protected areas where snow accumulates, the process is also intensive. There the soils have bleached upper horizons over thin horizons of iron accumulation.[5] Soils of this kind are more common in tundra areas immediately above treeline in subarctic regions.

Soils developed in materials derived from basic rocks, such as basalt, limestone, and calcareous shales, are similar in appearance to the acid soils described above, but pH values and base saturation are high. In some places, calcium carbonate has accumulated in the lower part of the soil.

With increasing distance from the treeline, the amount of organic matter added to the soil decreases and, because of lower temperatures and lower precipitation, chemical and biological processes such as oxidation and humification proceed at a slower rate. Well drained soils in the colder tundra areas may have only very thin or no dark upper horizons and thin brown B horizons. In the far north, where precipitation rates are very low and the vegetative cover is sparse, well drained soils that have no discernible horizon development are dominant. Other soils with no horizon development are the young sandy soils of active dunes bordering some major rivers[17] and the very gravelly soils of flood plains, low terraces, and steep colluvial slopes.

6.2 NATURAL PERTURBATIONS

6.2.1 Fire

Little is known of the role of fires in tundra ecosystem, yet they do occur. Fire removes most of the insulating layer of live vegetation and litter, damages or destroys the peat, and greatly changes the albedo of the surface. The result is a potential rapid increase in thermal erosion with increased runoff. A general account of vegetation recovery following a major fire in the tundra is given by Cody.[6] Nine years after the fire, grasses, sedges, and forbs recovered fairly well but lichens and mosses showed little recovery. With lichens playing an important role in the diet of caribou and reindeer, it is evident that burned areas will be lost to grazing for many years.

6.2.2 Drought

The tundra ecosystem is subjected to frequent droughts. Droughts have been sufficiently severe to permit serious tundra fires to occur. Any long term drought patterns are expected to affect the structure and productivity of an ecosystem.

6.2.3 Grazing

Overgrazing by the caribou and reindeer is quite common in the tundra ecosystem. These animals lead to selective removal of lichens through grazing. Vegetation composition and density are affected considerably. In the tundra, intense grazing activities tend to result in more woody and hardy shrubs.

6.3 MAN-MADE PERTURBATIONS

Disturbances to tundra vegetation due to activities of man derive from both winter and summer roads, pipelines, seismic lines, drill sites, crude oil spillage, tundra fires, living sites, and waste disposal.

The discovery of oil on July 18, 1968 near Prudhoe Bay on Alaska's arctic coastal plain (the North Slope) and subsequent flurry of oil and gas exploration and development have already had a pronounced impact on the tundra environment over a large area. In addition to the direct effects of oil development on the North Slope, there will be subsidiary effects in other parts of arctic tundra. Klein[12] described the impact of oil development in Alaska. Detailed descriptions of human impact of tundra are also given by Watson, Bayfield, and Moyes[22] and by Walker.[21]

Bliss and Wein[3] examined 25 seismic trail sites in the Low Arctic. By using control plots in adjacent vegetation, they were able to characterize the disturbance (Table 6-4). They concluded that wherever viable roots and rhizomes of shrubs, sedges, or grasses remained in the disturbed substrate, a 30 to 50 percent recovery in natural plant cover will occur in 3 to 5 years. Subsidence will occur in areas of high ice content. To date, there is little evidence that immediate reseeding can prevent ground ice melt and subsidence. Less detrimental effects from surface rutting and scraping were measured in the High Arctic.

Table 6-4. Change in conditions caused by seismic lines and winter roads with paired control plots in 1970 (adapted from Bliss and Wein[3]).

Community type	Year disturbed	Increased active layer (cm)	Increased bare soil (percent)	Decreased plant cover (percent)
Shrub-sedge-heath hummock	1965	26	63	65
Hummocks	1967	8	25	34
Wet sedge meadows	1969	1	5	7
Spruce-alder	1969	10	98	169
Upland winter road	1969	7	100	99

Revegetative studies are underway in several locations. Bliss and Wein[3] reported trails with 16 species seeded in 1970. At the rate of 20 kg per ha, Festuca rubra, Poa pratensis, Poa compressa, and Phleum alpinum have the best results in establishment and winter survival on mineral and peat soils. Alopecurus pratensis grew better on mineral soil. Fertilizer treatment with 100 kg per ha actual N and P_2O_5 doubled culm height over nitrogen fertilizer alone. The authors recommend sowing seeds with snowmelt in the spring or before snowfall in the autumn.

Experiments with oil spillage on terrestrial vegetation are few. Bliss and Wein[3] reported that oil poured directly on the foliage killed those leaves in contact with the oil in a few days. Some regrowth was evident in late summer from June treatment, but none from July treatment. Greater damage was evident in wet sedge and cotton grass tussock communities than in shrub communities. Microbial activity in the soil may increase tenfold, but the implications of this activity for the nutritional status of the community are not yet established. McCown and Brown[13] applied oil to the soil surface (avoiding foliage contact) and observed little immediate damage. Shoot growth response of *Dupontia* through the summer was not suppressed, except at the heaviest treatment of 12 liters per square meter, but root biomass seems to have been reduced. Observations in the second growing season showed reductions in stems per plot and in growth per stem. *Carex aquatilis* and *Eriophorum angustifolium* seemed less sensitive than *Dupontia*. To the extent that effects of oil spillage are manifest through limited root growth, vegetative response may not be apparent in aboveground tissue for one or more years.

A study of the effect of an air cushion vehicle (SK-5) on tundra vegetation[1,16] was measured quantitatively. The results clearly show that the exhaust air blows the litter and loosens organic matter, but principal damage was caused by dragging of the vehicle skirt on the surface. Although such effects change the albedo, the direct visible damage by the air cushion vehicle after 25 passes was often less than that of a single weasel pass.

In general, any disturbance which eliminates or greatly reduces plant growth, vegetative cover, or the organic litter or peat layer by any cause will increase thaw depth as a result of increased solar heat flux.[4] Greater understanding of response to disturbance in different landscape units is needed for regulating land use and for providing design criteria for land vehicles.

6.4 EFFECTS OF CLEANUP PROCEDURES ON TUNDRA

The concept of the fragility of the tundra has probably been too uncritically accepted as a convenient shibboleth by conservationists, in order to totally exclude resource development from the tundra. Undoubtedly, wet tundra, which may contain frozen water up to five or six times in excess of dry soil weight within the upper 40 meters, is fragile. This problem is rare in alpine tundra. Degree of disturbance potential could be mapped on a regional scale according to water content, grain size and vegetation physiognomy. However, there are other reasons behind the concept of the fragile tundra that relate specifically to plant adaptation and community structure and primary productivity considered both as daily rates and total season's production. Bliss[2] has argued that the very limited number of plant species in the Arctic is a real indication of fragility of the ecosystem since adverse impact on a very few species may damage the whole: the potential for recovery may be proportional to plant community variability. Dunbar[8] emphasizes that a proper consideration of "fragility" hinges on one's definition of stability. A steady-state situation, which may pertain to arctic lakes and perhaps also to tundra vegetation, is vulnerable to excessive disturbance since the system cannot adapt. Another type of stability is represented by a system which can absorb disturbance and return to its previous state. Tundra animal populations undergo drastic fluctuations but recover, perhaps as a result of their ability to draw on outside areas. Dunbar concludes that simplicity of an ecosystem, coupled with slow growth rates, leads to vulnerability to disturbance which can be tolerated only if the spatial scale is large (as in the Arctic) and the time scale is sufficiently long.

(0-1) Natural Rehabilitation

Natural rehabilitation after a contamination of land in the tundra environment is suggested as a high priority treatment for cleanup. Ecosystem recovery tends to follow ecologically normal and predictable successional trends, i.e., patterns following damage from most postulated contaminants are similar to those following fire, logging, or shipping of top soil and other natural catastrophic events. Bliss[2] reported that nine years after a fire, grasses, sedges and forbs recovered fairly well but lichens and mosses showed little recovery. It is assumed that in case of a contamination of an area in the tundra environment, ecological recovery will follow a different pattern. The area would still have its litter and organic cover and will not be subjected to a deeper thaw during summer. The vegetation in a tundra ecosystem has a higher below-ground biomass production and would provide better soil binding against water erosion during the summer thaws.

(1-1) Chemical Stabilization

The cleanup by chemical stabilization is to reduce the infiltration rate and thereby reduce the mobility of contaminants into the vadose zone. The chemical stabilization will not be practical in the tundra environment.

(1-2) Clearcutting Vegetation

Removal of woody shrubs by clearcutting can be used as a possible technique for cleanup. Along the Alaska pipeline route, the tundra vegetation was removed by clearcutting of woody plant species and shrubs. In arctic and alpine environments the plants are small, close to the ground, and often widely separated by bare soil or rock. Unlike the situation within a forest, the modification of microclimate by vegetation is minimal and the physical environment dominates the vegetation. In such open and windy places, the effects of microenvironment are pronounced. Even a few centimeters difference in microtopography makes a marked difference in soil temperature, depth of thaw, wind effects, snow drifting and resultant protection to vegetation. The microtopographic effects may be caused by a rock, a soil polygon rim or by another plant itself. The removal of larger vegetation plants would result in an uneven distribution of snow and thus differential distribution of soil moisture, heat exchange, and protection from windblast.

It is assumed that the clearcut areas will not be disturbed as far as the litter and organic horizons of the tundra soils, and that the clearcut areas will be replanted or reseeded.

General effects of clearcutting are described in the coniferous forest land type (see Chapter 4). Clearcutting of the woody shrubs in a small area within the tundra ecosystem can have extreme effects on the microclimate and the hydrological factors, since so much of the alpine or arctic landscape is characterized by scattered woody shrubs and forbs. Removal of the vegetation will affect the snow and soil moisture distribution due to microtopographical changes created by the removal of larger shrubs. Soil temperature within the clearing will increase and there would probably be a deeper and earlier thaw during the summer. The effects of clearcutting on heat balance, soil moisture, precipitation, runoff, and on wildlife have been described in the coniferous forest land type (Chapter 4). These effects of clearcutting in tundra environment would be somewhat different in magnitude but there are no data available on these effects of clearcutting in a tundra environment.

(1-3) Stumping and Grubbing

Removal of roots and stumps in a tundra environment would cause considerable disturbances. The practice would create depressions and other microtopographical disturbances in the treatment area. As mentioned earlier, the effects of microtopographical changes in a tundra environment are quite drastic and would affect snow distribution, heat exchange, depth of thaw, soil moisture, soil temperature, and surface runoff. Surface litter and the organic layers on the surface would also be disturbed.

Due to the drastic nature of disturbances such as increased potential hazards for soil erosion and sediment losses and deeper thawing and freezing that would be caused by a stumping and grubbing operation, the practice of vegetation removal by stumping and grubbing should not be used as a contaminant cleanup technique in the tundra environment.

(1-4) Scraping and Grading

The surface alteration through scraping and grading in the tundra environment would require some prior clearcutting and removal of stumps from the treatment area. Surface litter and some organic matter would be removed in the process of scraping. Grading processes may even expose some mineral soil horizons. The insulative effects of vegetation, surface litter and organic matter would be destroyed and therefore the heatflow would not be insulated. Soil thawing and freezing would be relatively faster and deeper.

Infiltration rates would decrease with an increase in surface runoff and water erosion. The frequent freeze-thaw cycles at the soil surface coupled with the common presence of permafrost not far beneath the surface results in physical frost-thrusting of soil, rocks and plants wherever water is abundant. Surface scraping and grading would enhance such soil frost activity which produces various kinds of polygons, stone nets, and solifluction terraces. These disturbances would make the edaphic environment unstable. Such widespread soil frost activity, combined with the frequent presence of permafrost not far below the soil surface, would have a significant effect on getting the vegetation reestablished in the treatment area. Vegetational patterns in arctic and alpine tundra are strongly shaped by such soil frost activity.[11]

Other effects of surface alteration in the tundra environment would be similar to those described in the coniferous forest land type (see Chapter 4).

(1-5) Shallow Plowing

Shallow plowing operations for contaminant cleanup would not be practical for the tundra land type.

(1-6) Deep Plowing

Deep plowing operations for contaminant cleanup would not be practical for the tundra land type.

(1-7) Soil Cover Less Than 25 cm

Top soil dressing the treatment area would cover up the surface litter and organic matter horizons. Ecological impacts of the treatment would vary according to the depth of top soil application. The treated areas should be reseeded or replanted for getting vegetation reestablished.

Beneficial effects of top soil dressing would be in terms of better insulation against heatflow, thus slowing soil thawing and freezing. Infiltration rates would also increase. However, lack of vegetative cover would make the soil surface vulnerable to the soil losses due to wind and water erosion.

(1-8) Soil Cover to 25 to 100

Same as for treatment 1-7.

(2-1) Remove Plow Layer

Removal of surface soil (10 cm) from a contamination area in the tundra environment would be similar to scraping and grading practices. Surface litter and organic matter layers would be disturbed. Ecological impacts of this operation would be similar to those described under Scraping and Grading (1-4).

(2-2) Remove Shallow Root Zone

Removal of shallow root zone soil (<40 cm) would also be similar to the operations for surface alterations. The ecological disturbance and impact are very similar to those described under Scraping and Grading (1-4).

(2-3) Remove Scraping and Grading, Mechanically Stabilize

Surface scraping and removal of a shallow layer (<5 cm) from a contaminated area in the tundra environment would be impractical. Tundra soils have thick layers of litter and organic horizons on the surface. Moreover, the removal of a shallow layer from soil surface would disturb the area and would result in loss of insulative layer against heat flow. The operation would cause increased frost action and unstable surface conditions. Exposed surface would not be suitable for mechanical stabilization.

(2-4) Remove Plow Layer, Mechanically Stabilize

The technique would not be applicable for the same reasons described above (2-3).

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

Would not be practical.

(2-6) Remove Scraping and Grading, Chemically Stabilize

Chemical stabilization is not practical in the tundra environment.

(2-7) Remove Plow Layer, Chemically Stabilize

Chemical stabilization would not be practical.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

Chemical stabilization would not be practical.

(3-1) Barriers to Exclude People

Exclusion of people from the treatment area would not affect the ecology of tundra.

(3-2) Exclude Large Animals

Exclusion of large herbivores such as reindeer, caribou or musk oxen would reduce local grazing pressure and result in increased surface biomass, increased insulation by organic material and a gradual change in permafrost depth. Since large herbivores can cause a decrease in lichens and in increase in woody shrubs, continued exclusion might lead to a shift in relative abundance of some species, but otherwise would not affect the ecology of the area.

Herding arctic animals follow set migration paths; however, unless the exclusion fence blocked a natural barrier such as a mountain pass or river ford, even the largest fenced area should have little effect on gross animal movement.

(3-3) Exclude Large and Small Animals

Exclusion of the small and large animals from the treatment area would help the process of natural restoration. There would be no disturbances caused by browsers and grazers. Large animals like reindeer, caribou and musk oxen, and small animals like lemmings, have quite a grazing impact on the ecology of the tundra environment. The other impacts are due to compaction, surface soil disturbances and physical damage to the vegetation.

(4-1) Asphalt Hard Surface Stabilization

This treatment is outside the scope of work of this study. However, experience in construction of arctic roadways and air strips suggests that changes in the insulation properties of the surface and the resultant change in the depth of permafrost would be the major effect. Lachenbruch has detailed the procedures for calculating the proper thickness of gravel fill for different surface materials and climatic conditions that will minimize the effect on the permafrost layer.

(4-2) Concrete Hard Surface Stabilization

This treatment is outside the scope of work of this study.

(5-0) Application of Sewage Sludge

This treatment is outside the scope of work of this study.

(6-1) High Pressure Washing

This treatment is outside the scope of work of this study.

(6-2) Flooding to 30 cm

This treatment is outside the scope of work of this study.

(7-0) Soil Amendments Added

This treatment is outside the scope of work of this study.

6.5 RECOVERY AFTER CLEANUP

6.5.1 Irreversible Changes

The cleanup techniques described earlier for the tundra environment would not have irreversible impact on the ecology. However, the harsh nature of the tundra environment, relatively short growing season and low temperatures during the growing season would make the vegetative regeneration, ecological succession and animal recovery very slow processes.

6.5.2 Rates of Recovery

The sensitive nature of the tundra ecology to disturbances has led to the concept of "fragile" tundra. Figure 6-1 illustrates the series of events which follow the damage of tundra vegetation. The altered plant cover reduces both surface insulation and albedo, and more heat is absorbed by the soil with the result that there is a greater depth of thaw and both subsidence and erosion may ensue. Such disturbance will ultimately recover due to the natural homeostatic mechanisms in ecosystems which bring about new equilibrium. Unfortunately little is known about the time factor in these recoveries; it may range from a few to hundreds of years. In Figure 6-1, well drained sites where the ground contains little ice show slight changes and recovery to a new, little altered equilibrium is rapid. However, on wet sites containing much ground ice greater damage is caused, and recovery will be slow and may result in a different vegetation when equilibrium is regained.

One of the greatest concerns of ecologists is the degree to which tundra vegetation can be disturbed and yet reestablish a turf within three to five years prior to thermokarst development. According to Brown et al.,[4] even the replacement of mulch results in nearly as deep a thaw as does the removal of total plant cover, 61 cm versus 75 cm, respectively. The control plots averaged

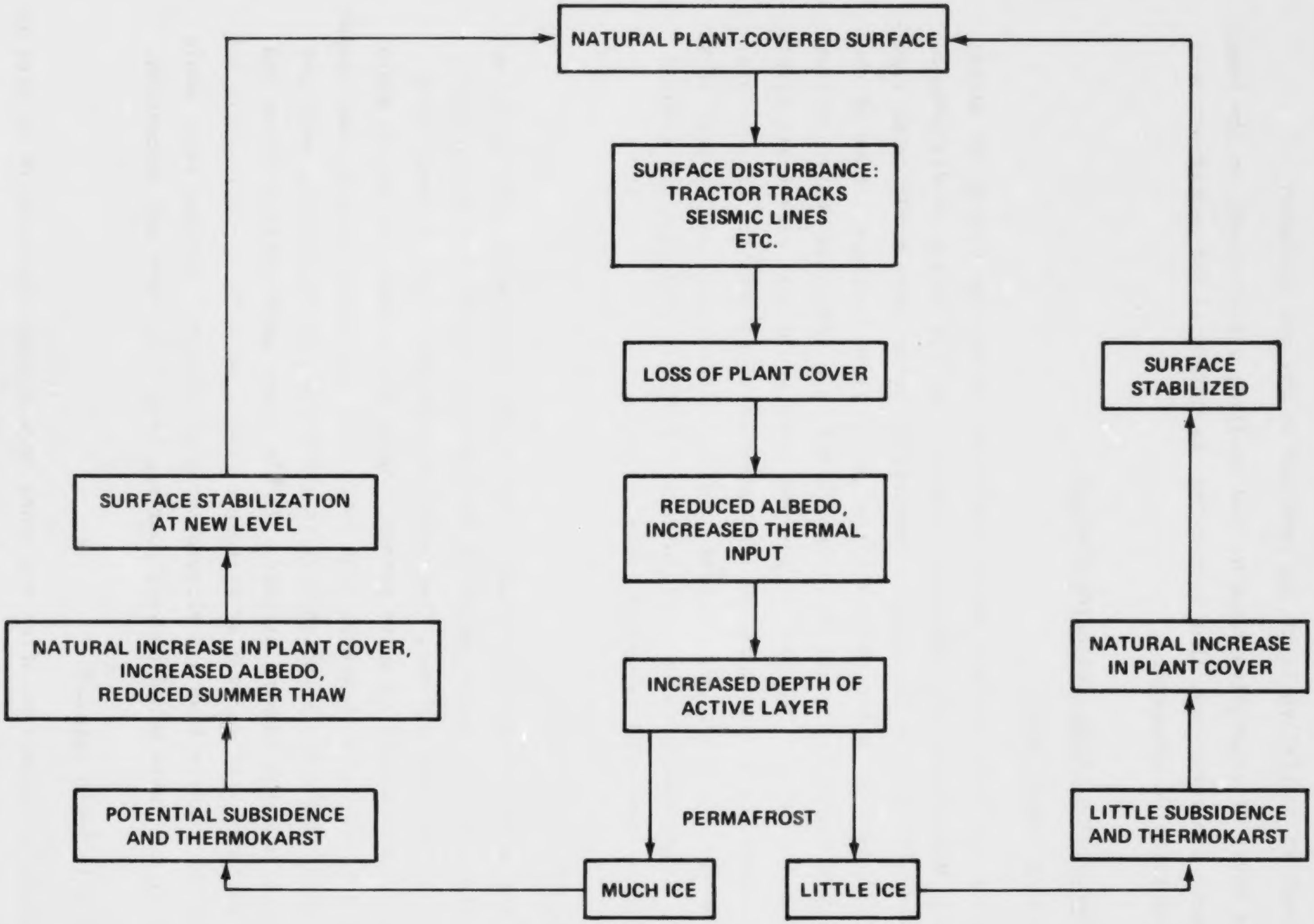
NATURAL PLANT-COVERED SURFACE
SURFACE DISTURBANCE: TRACTOR TRACKS SEISMIC LINES ETC.
LOSS OF PLANT COVER
REDUCED ALBEDO, INCREASED THERMAL INPUT
INCREASED DEPTH OF ACTIVE LAYER
PERMAFROST
MUCH ICE
LITTLE ICE
POTENTIAL SUBSIDENCE AND THERMOKARST
NATURAL INCREASE IN PLANT COVER, INCREASED ALBEDO, REDUCED SUMMER THAW
SURFACE STABILIZATION AT NEW LEVEL
LITTLE SUBSIDENCE AND THERMOKARST
NATURAL INCREASE IN PLANT COVER
SURFACE STABILIZED

Figure 6-1. A word model illustrating the sequence of events in the recovery of damaged arctic tundra vegetation (from Bliss[2]).

32 cm for maximum summer thaw. The changed albedo is probably the major factor even though an insulative layer was returned in the one treatment.

The rates of vegetative recovery and seedling establishment in the tundra environment are very slow, thus increasing the potential for permafrost melt and thermokarst development.

6.5.3 Succession Stages Following Cleanup

6.5.3.1 First Year--

During the first growing season after the cleanup the ecological succession would depend upon the nature of treatment and the degree of disturbances associated with it. In the natural restoration areas there would be no significant disturbances in the surface litter and organic horizons. Some of the woody shrubs which have quite an extensive and well insulated rooting system will start sprouting. Grasses, sedges and forbs would also regenerate fairly well. Lichens and mosses would not show much of regeneration. Cleanup procedures such as stumping and grubbing, surface alterations, and removal of surface soil layers would cause major surface disturbance and thus the treated area would be subjected to severe frost action.

6.5.3.2 Fifth Year--

In the natural regeneration area, and in the areas which were fenced out to keep the people or large and small animals out, the surface disturbances and frost action were minimum. The vegetative recovery for grasses, woody shrubs and forbs should be quite normal. Again the lichens and mosses would have a relatively slow recovery. The seeds from the nearby sources, and sprouting of shrubs and grasses, which have an extensive rooting system, would get the vegetative establishment started. In the areas where surface litter and organic horizons were removed or disturbed, there would be a considerable increase in the frost action and microtopographic changes. Erosion rates would be quite high. There would be very poor vegetative recovery and succession.

6.5.3.3 Tenth Year--

Vegetative succession after ten years from cleanup treatment of an area in the tundra environment would have a near normal vegetative cover recovery except for lichens and mosses. This is based on an assumption that there were no major disturbances to the surface litter and the organic horizons. The situation would be different in areas where the cleanup operation disturbed the insulating layers of litter and organic matter and changed the albedo considerably. The vegetative establishment would have a very slow start in the disturbed areas. However, during the first ten years after the treatment, most of the frost action induced disturbances and land subsidence would have already taken place and natural or man induced revegetation would start taking place on a new surface.

6.5.3.4 Climax--

It would be very difficult to evaluate the post cleanup treatment effects on vegetative recovery and succession to a climax stage. Differences in ecological conditions after fifty or 100 years after different cleanup treatment are not expected. In terms of geological time, there would be no differences due to different cleanup treatments reflected in the climax vegetation.

6.6 QUANTITATIVE ASSESSMENT OF CLEANUP IMPACTS

The preceeding sections of this chapter have clearly shown that any cleanup procedure (except the benign exclusion by barrier) involves major perturbation of the tundra biome that will result in long lasting environmental effects. Quantitative assessment of the ecological differences among the various procedures is meaningless since any procedure which would result in removing a hazardous material will result in approximately the same ecosystem desruption.

6.7 CONCLUSIONS

Cleanup techniques result in changes in albedo, in microclimate, in thermo-equilibrium, and in the relationships between unfrozen ground and permafrost. To a large extent homeostasis is maintained by the mosses and lichens. During the short summer growing period when the sun is the warmest, there is an abundance of standing melt water on the tundra. Moss has a very high evapotranspiration rate that tends to keep the air layers closest to the ground cool. The lichens prevent the direct rays of the sun from striking the ground surface. The interaction of cool air, cool water and no direct sunlight permits only a minimum melting of the permafrost and leads to the formation of a shallow active area where plant growth takes place.

If the cover material of the tundra is disturbed in any way the active layer becomes thicker while the permafrost table is lowered. The thicker active layer collects additional water from surrounding areas. This additional water leads to formation of frost heave structures, thermokarsts and soil movement through solifluction.

All cleanup techniques alter the cover material and are therefore deleterious to the tundra.

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CHAPTER 7
COASTAL INTER-TIDAL MARSHES

7.1 OVERVIEW

Heavy vegetational development takes place where the soil is waterlogged or covered by shallow standing water for all or most of the year. Where this vegetation is dominated by grasses, reeds, sedges, and other non-woody types the development is referred to as a marsh. If the vegetation is largely bushes and trees, it is called a swamp. Coastal marshes and swamps represent some of the highest zones of primary productivity in the world. Some marshes exhibit a net primary productivity of greater than 3,000 $g/m^2/yr$ (Table 7-1). In coastal marshes, however, less than 10 percent of the net production of the ecosystem is consumed by grazing herbivores, mostly insects in this case, and at least 90 percent follows the detritus path of energy flow. The bulk of the animals in the coastal marsh such as shellfish, snails, and small crabs, seem to obtain their energy directly or indirectly from detritus.

The five mechanisms and conditions that maintain this biological energy flow at rates far superior to the adjacent ecosystems are: (1) Tidal action promotes a rapid circulation of nutrients and food, and aids in the rapid removal of the waste products of metabolism. (2) A diversity of plant species and life forms provides a continuous photosynthetic carpet despite variable physical conditions. The three major life forms of autotrophs that work together to maintain a high gross production rate are: (a) phytoplankton; (b) benthic microflora—algae living in and on mud, sand, rocks, or other hard surfaces, and bodies or shells of animals; (c) large attached plants—the seaweeds, submerged eel grasses, and emergent marsh grasses. (3) A coastal marsh is often an efficient nutrient trap that is partly physical (differences in salinities cause vertical as well as horizontal stratification of water masses) and partly biological. (4) A year-round primary production by a succession of "crops," even in northern regions. (5) Close contact between autotrophic and heterotrophic layers.

Table 7-1. Net primary production and plant biomass for major ecosystems and for the earth's surface (from Whittaker[12]).

	AREA * 10^6 km²	NET PRIMARY PRODUCTIVITY, PER UNIT AREA † dry g/m²/yr		WORLD NET PRIMARY PRODUCTION ** 10^9 dry tons/yr	BIOMASS PER UNIT AREA ‡ dry kg/m²		WORLD BIOMASS ** 10^9 dry tons
		normal range	*mean*		*normal range*	*mean*	
Lake and stream	2	100–1,500	500	1.0	0–0.1	0.02	0.04
Swamp and marsh	2	800–4,000	2,000	4.0	3–50	12	24
Tropical forest	20	1,000–5,000	2,000	40.0	6–80	45	900
Temperate forest	18	600–2,500	1,300	23.4	6–200	30	540
Boreal forest	12	400–2,000	800	9.6	6–40	20	240
Woodland and shrubland	7	200–1,200	600	4.2	2–20	6	42
Savanna	15	200–2,000	700	10.5	0.2–15	4	60
Temperate grassland	9	150–1,500	500	4.5	0.2–5	1.5	14
Tundra and alpine	8	10–400	140	1.1	0.1–3	0.6	5
Desert scrub	18	10–250	70	1.3	0.1–4	0.7	13
Extreme desert, rock and ice	24	0–10	3	0.07	0–0.2	0.02	0.5
Agricultural land	14	100–4,000	650	9.1	0.4–12	1	14
Total land	149		730	109.		12.5	1,852.
Open ocean	332	2–400	125	41.5	0–0.005	0.003	1.0
Continental shelf	27	200–600	350	9.5	0.001–0.04	0.01	0.3
Attached algae and estuaries	2	500–4,000	2,000	4.0	0.04–4	1	2.0
Total ocean	361		155	55.		0.009	3.3
Total for earth	510		320	164.		3.6	1,855.

* Square kilometers × 0.3861 = square miles.

† Grams per square meter × 0.01 = t/ha, × 0.1 = dz/ha or m centn/ha (metric centers, 100 kg, per hectare, 10^4 square meters), × 10 = kg/ha, × 8.92 = lbs/acre.

** Metric tons (10^6 g) × 1.1023 = English short tons.

‡ Kilograms per square meter × 100 = dz/ha, × 10 = t/ha, × 8922 = lbs/acre, × 4.461 = English short tons per acre.

Coastal marshes develop on relatively flat terrain between the limits of normal high and low tide of protected bays, estuaries, and lagoons. They are dominated by a few species of tall emergent reed-like vegetation which are tolerant of rhythmic submergence and saline conditions. The water may be nearly fresh or nearly marine or highly variable in salinity, and flushing occurs with each tidal cycle. Within saltwater marshes there is a gradual build-up of organic peat deposited by the vegetation itself. Highly dendritic tidal creeks dissect the marshes and serve as avenues of entrance and egress of the tidal waters which alternately flood and drain the marshes. Because of their adaptations to the intertidal zone, salt marshes are highly sensitive to even minor change in water levels.

The coastal marsh ecosystem lies from a few feet above sea level to a few feet below it. Hence, it is subject to the ebb and flow sweeping action of tidal currents, and all must be tolerant of some salinity change. All trap suspended nutrients by slowing down the water currents, and they all provide shelter and food for a variety of small brackish water and marine animals. These are among the most productive ecosystems of the world with annual production rates running around five tons per acre. Much of this plant production becomes available as organic detritus which provides the chief food base for the coastal fish and shellfish populations of commercial importance. Without these important production and nursery areas, our coastal seafood resources would suffer severe decline.

Although tolerant of short-term inundations with fresher or more saline waters and even short-term exposure to the air, these systems cannot tolerate long-term changes in these environmental factors. Drying of the habitat or major intrusion of fresh- or saltwater has been shown to change the composition of the dominant vegetation with long-term erosion of the productivity of these systems.

The marsh vegetation is dominated by several species of the tall *Spartina* grass and to lesser extents by other emergent species such as *Distichlis*, *Juncus*, and *Salicornia*. Around the bases of these plants and on the surfaces of old leaves grow a variety of filamentous algae including blue-green, brown, and red algal types. On the mud flats between the bases of the plants grow a variety of

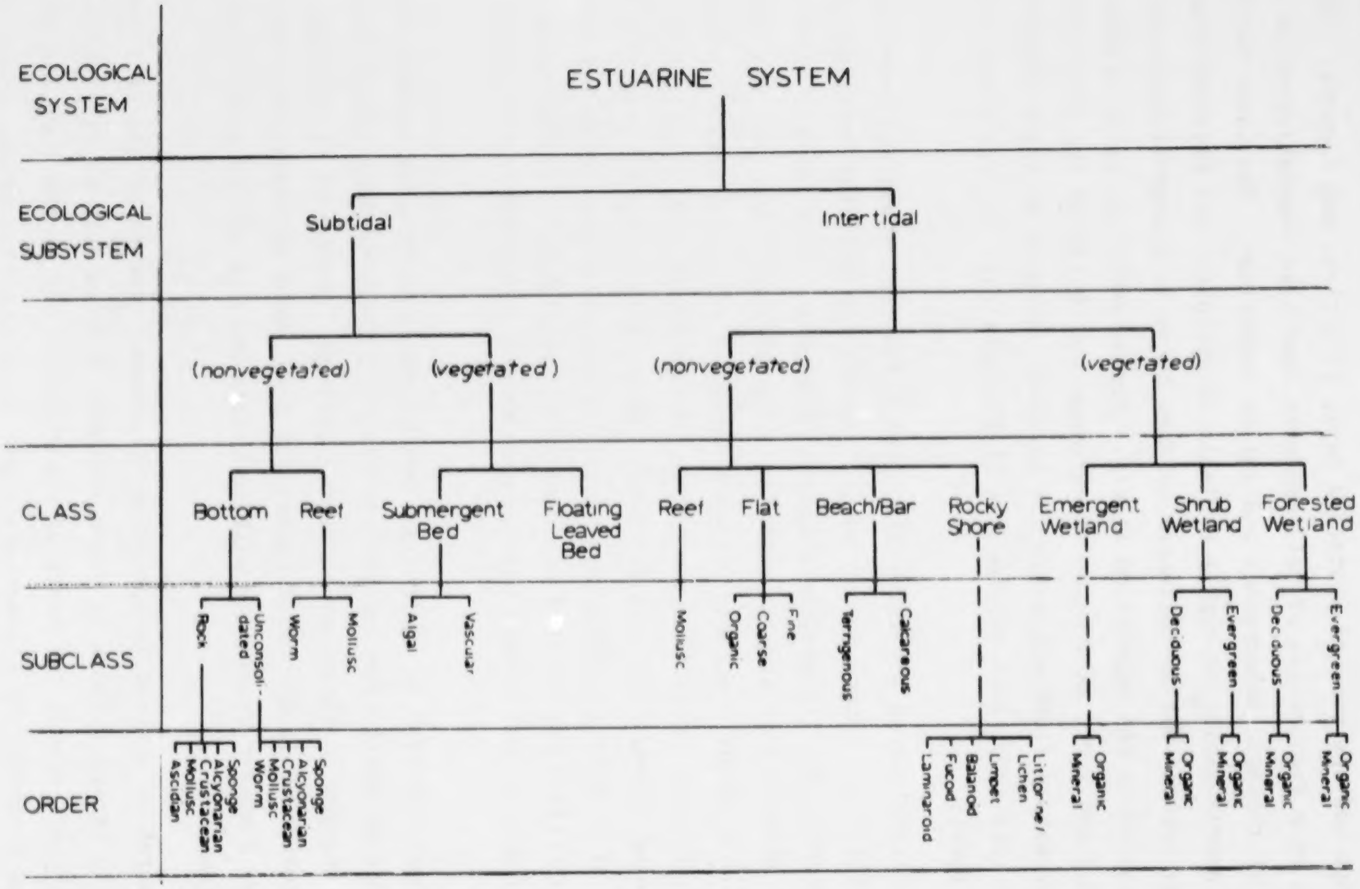
ECOLOGICAL SYSTEM
ESTUARINE SYSTEM
ECOLOGICAL SUBSYSTEM
Subtidal
Intertidal
(nonvegetated)
(vegetated)
(nonvegetated)
(vegetated)
CLASS
Bottom
Reef
Submergent Bed
Floating Leaved Bed
Reef
Flat
Beach/Bar
Rocky Shore
Emergent Wetland
Shrub Wetland
Forested Wetland
SUBCLASS
Rock
Unconsolidated
Worm
Mollusc
Algal
Vascular
Mollusc
Organic
Coarse
Fine
Terrigenous
Calcareous
Deciduous
Evergreen
Deciduous
Evergreen
ORDER
Ascidian
Mollusc
Crustacean
Alcyonarian
Sponge
Worm
Mollusc
Crustacean
Alcyonarian
Sponge
Laminaroid
Fucoid
Balanoid
Limpet
Littorine/Lichen
Mineral
Organic
Mineral
Organic
Mineral
Organic
Mineral
Organic
Mineral
Organic

Figure 7-1. Diagram of the wetland classification hierarchy for the estuarine ecological system to the order level (from U.S. Department of Interior[9]).

diatoms and blue-green algae. Plant production of the marsh is dependent upon all three groups of producers, the tall emergent species, the filamentous attached forms, and the mud flat inhabitants.

Only grasshoppers and a few birds such as seaside sparrows may be found among the tall Spartina grass, but the water and mud flats are teeming with animal life. This includes snails, mussels, and oysters, as well as a variety of worms, crabs, shrimp, and small fishes. Many of the crabs, shrimp, and fishes are juveniles of species which support the commercial catch as adults. Large numbers of shore and wading birds forage in these marshes at low tide.

Studies have shown that there is a regular export of decomposing organic matter through the tidal creeks to the estuaries, but the major export occurs when storms inundate the marshes with high water and flush out great quantities of organic matter to the estuaries and the continental shelves.

7.1.1 Occurrence of Coastal Marshes

Coastal marshes (or intertidal emergent wetlands) are recognized as an ecological class within the Estuarine System of a wetland classification (Figure 7-1). There are nearly 70 million acres of natural wetlands in the continental United States of which coastal marshes total about 17.5 million acres.

7.1.2 Related Land Types

Coastal marshes as an ecosystem type are very similar to coastal swamps and grass flats. All are emergent wetland ecosystems (Figure 7-1).

A coastal swamp is an association of mangrove trees which grows in the sea or in the water of sheltered bays and estuaries of subtropical regions. The average water depth may be from a few inches to about four feet. Extensive prop root systems reduce the action of waves and tidal currents and produce a characteristic set of internal environmental conditions. Water flow is greatly reduced. Sedimentation is high, and much organic matter accumulates. Oxygen levels are low, and the environment is in many respects similar to that of anaerobic submerged soils. Strong gradients in oxygen content and other factors exist from the periphery to the interior of the swamp. In some cases, saltwater swamps grade inland into saltwater marshes.

Coastal swamps are dominated by the low, bush-like red, black, and white mangrove trees. A few other shrubs and vines may also be present. The extensive root systems developed by the mangroves provide surfaces for attachment of filamentous algae, and the surface muds may support large and productive diatom floras. Large numbers of oysters are often found attached to the mangrove roots; a variety of small crabs, shrimp, and fishes feed on the organic forage around the roots and mud flats at low tide; and birds nest in the branches of the mangroves.

Grass flats or submarine meadows consist of a few species of grasses which are tolerant of continual submergence in salt and brackish waters. They are normally found from the low water line to a depth of about three feet, but they may extend considerably deeper in very clear waters. Although seldom found in very strong current, they are most luxuriant where there is moderate flushing. The long flat blades of the dense beds protect the bottom from erosion, and extensive deposition creates a substratum of finely particulate, high organic muds. Sufficient water penetrates the beds to maintain high oxygen levels in the water above the bottom.

The grass flats are dominated by eelgrass (*Zostera* spp) in northern latitudes or by turtle grass (*Thalassia* spp) or manatee grass (*Cymodocea* spp) in the more tropical areas. The long grass blades are often clothed with a layer of attached filamentous algae which produce organic matter and which also act as brushes to remove suspended matter from the flowing water above. Many small animals live among the stems and roots of the grass beds, and larger fishes and birds forage there.

7.2 NATURAL PERTURBATIONS

Coastal marshes are generally considered to represent a seral stage in the succession of water to dry land. In areas with relatively stable climatic conditions, succession is extremely slow and the marsh maintains the same appearance year after year. In other areas, violent climatic fluctuations cause coastal marshes to revert to an open water phase in some years and the concept of succession in the normal sense of the word has little meaning. Fire has been shown to play an important role in maintaining coastal marshes. Coastal marshes can recover from fires in a couple of years if the fire does not burn down to the bare soil and thereby permit excessive erosion.

Large storm systems (e.g., hurricanes) can cause extensive damage to coastal wetlands due to erosion and excessive freshwater runoff. Erosion physically disrupts the marsh while the freshwater inflow may temporarily upset biota adapted to marine or estuarine conditions. These effects are generally short term and marsh recovery would be expected within a few years. Studies of natural perturbation show effects on primary and secondary productivity but these perturbations are well within the range of homeostatis within the marsh ecosystem.

7.3 MAN-MADE PERTURBATIONS

7.3.1 Impact on Baseline Ecosystem Components

The coastal marsh is a semi-aquatic system in equilibrium with the prevailing climatic, hydrographic, geological, and biological forces of the coast. Even slight modification in the level of the water table or the rate of surface freshwater flow greatly modifies the biological characteristics of the system. Although the coastal marshes vary greatly in detail, a more or less typical marsh has freshwater vegetation at the landward side, saltwater vegetation at the marsh is drained by highly dendritic tidal creeks which empty into the bay or estuary. Freshwater entering along the upper edges of the marsh drain across the surface and enter the tidal creeks.

Many of the marshes of the Atlantic and Gulf coasts have undergone great attrition in recent years, primarily as a result of levee and canal construction. A levee placed across the upper end of a coastal marsh has the following primary effects:

- cuts off all distributaries feeding the marsh
- prevents freshwater flooding
- prevents annual flushing
- prevents annual renewal of sediments and nutrients
- ends formation of new marshes.

Canals which lace the coastal marshes for navigation, pipelines, or mosquito control have the following primary effects:

- intercept and carry off freshwater drainage
- block freshwater from flowing across the portion of the marsh that is seaward of the first canal
- rapidly carry off freshwater to the bay or estuary

- lower the water table
- permit saltwater intrusion well into the marsh proper.

7.3.2 Unassisted Recovery Sequence

The biological consequences are clear. On the Atlantic coast where subsidence rates are fairly slow, the marsh vegetation gives way to dry land vegetation with accompanying changes in the animal populations. Bourn and Cottam[2] reported on a detailed 10-year study of the fate of a drained coastal marsh in Delaware. Prior to canalization, 90 percent of the marsh vegetation was saltmarsh cordgrass (Spartina alterniflora) with smaller amounts of other marsh species, especially at higher elevations. A few open water areas supported luxuriant growths of widgeongrass (Ruppia maritima) and other submerged aquatic species.

Ten years after ditching had taken place the wetland plants had been reduced to small groups in the remaining low spots and along canal margins. Groundselbush (Baccharis halimifolia) dominated the plant community which now was made up largely of dry land species such as asters, goldenrods, terrestrial grasses, and young trees (pine, juniper, sweetgum, maple, and hawthorn). Aquatic animal populations of the ditched areas had been greatly reduced in areal extent and in density, even in the wetland habitat which still remained (Table 7-2). The density of the total invertebrate population was reduced from 39 to 97 percent in the various samples, and the mollusks and crustaceans, which make up important food items for many fishes and shore birds, were reduced 32 to 100 percent. Open aquatic areas, which formerly supported widgeongrass and other important duck foods, had been reduced to mud flats and dry land. Thus, the wetland habitat, important in the production of fishes, shellfishes, ducks, and wading birds, had given way to land with its low wildlife values.

On a subsiding coast, such as occurs in southern Louisiana, elimination of the normal freshwater and sediment input upsets the land-water equilibrium, and the subsiding marsh tends to become an open water area. This tendency is intensified by canals which drain the marshes, enhancing compaction. These canals tend to grow wider as a result of marginal subsidence, wave erosion, and disturbance from boat traffic. Plant production by marsh grasses of the Gulf coast is very high, exceeding 10 tons per acre per year and a great deal of additional plant production occurs in the marshes due to attached algae, mud flat diatoms, and

Table 7-2. Effects of ditching a Delaware tidewater marsh on the aquatic invertebrate populations. Vegetational zones are characterized by the dominant plant species. Six-foot square quadrants were sampled for comparison of invertebrate density in the drained and undrained sections of the marsh, and they represent three consecutive years of sampling during the months of April-December (from U.S. Environmental Protection Agency[11]).

Vegetation Zones	Feet above mean sea level (for the undisturbed marsh)	Percent reduction of the invertebrate populations	
		Total invertebrates	Mollusks and crustaceans
Saltmarsh cordgrass (*Spartina alterniflora*)	1.88-2.93	39-82	32-95
Saltgrass (*Distichlis spicata*)	2.35-2.90	64-88	82-94
Saltmeadow cordgrass (*Spartina patens*)	2.58-3.32	41-97	55-100
Saltmarsh bulrush (*Scirpus robestus*)	2.75	50-97	58-98

phytoplankton in the shallow waters. A large fraction of this organic matter is exported through tidal creeks to nearby bays and estuaries. When the marsh becomes an open water area, however, production is apparently reduced, and instead of exporting organic matter, the area becomes a nutrient sink. Birds and mammals no longer find food and refuge among the marsh grasses, and canals create migrational barriers to terrestrial and semi-terrestrial animals which utilize the marsh. Complete shifts in vegetation accompany increased salinity and subsidence.

Saltwater intrusion increases the salinity of the marshes, eliminating the broad mixing zone so important as nursery grounds for juvenile fishes, shrimp, and crabs. In deeper channels where reducing conditions prevail, large quantities of hydrogen sulfide are produced which are toxic to the marsh grasses[8] and to the aquatic animals. Acid conditions of the canals may also result in release of heavy metals from the sediments. As a result of habitat loss, decreased food supply, increased salinity, and increased hydrogen sulfide, populations of aquatic animals are adversely affected. Moore and Trent[7] compared oyster production in natural and canalized marshes. They found that in the altered marsh the set of young oysters was reduced by over 90 percent, juvenile growth was slowed, average length was reduced by 36 percent, weight was reduced by 27 percent, and mortality was increased by 39 percent. As a result of these and other studies, St. Amant (unpublished) has concluded that lack of freshwater has drastically modified the ecology of coastal marshes and severely damaged production of valuable oysters, shrimp, fur animals, and waterfowl.

In areas of eroding shorelines where dredged spoil has been used to support vegetation, both seeding and transplanting methods have been used to redevelop the flora. Both methods have been highly successful and after two growing seasons, little or no difference existed in appearance and primary productivity between these new marshes and long established natural marshes.

The methods of soil removal are dependent on the depth and characteristics of the unstable material as well as upon the nature of the underlying stable substrate (Figure 7-2). Where depths of unstable material do not exceed about 10 feet a dragline, shovel, or dredge may be used to excavate the unstable material to sufficient width. The excavated material handled by dragline or shovel is usually side cast beyond the excavation, forming a spoil bank, and it must be removed a sufficient distance to prevent lateral displacement back into the excavation.

Where deeper unstable deposits are encountered (about 10 to 25 feet), displacement methods are commonly used. In such methods the fill is advanced by end-dumping and placement with a bulldozer in a V-shape (i.e., highest along the central crest). Fill height is increased until the load is sufficient to produce failure in the underlying unstable materials, displacing them laterally. Displacement may be accelerated by jetting with water prior to, during, and after displacement of the fill. As the fill settles, additional material must be placed to maintain the grade. The weight of the fill will cause lateral compression in the displaced materials which may result in settling and horizontal movement of the shoulders for several years.

Displacement of unstable materials under the fill may also be accomplished by blasting. In the "underfill" technique the surface layers are broken with equipment or light charges, the fill is placed, and explosives are then positioned through the fill in jet holes or casings. Usually one to three rows of explosives

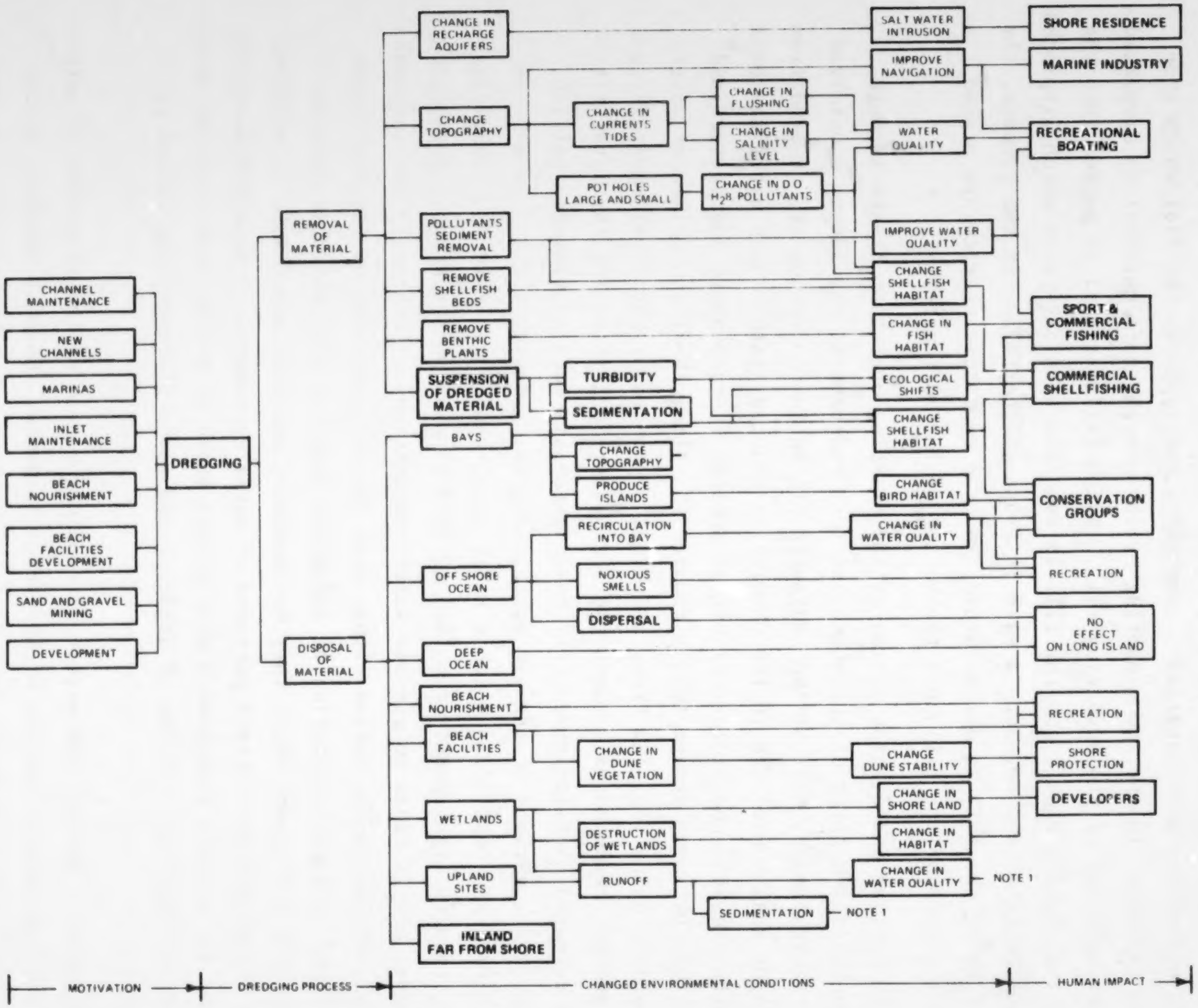
CHANNEL MAINTENANCE
NEW CHANNELS
MARINAS
INLET MAINTENANCE
BEACH NOURISHMENT
BEACH FACILITIES DEVELOPMENT
SAND AND GRAVEL MINING
DEVELOPMENT
DREDGING
REMOVAL OF MATERIAL
DISPOSAL OF MATERIAL
CHANGE IN RECHARGE AQUIFERS
CHANGE TOPOGRAPHY
POLLUTANTS SEDIMENT REMOVAL
REMOVE SHELLFISH BEDS
REMOVE BENTHIC PLANTS
SUSPENSION OF DREDGED MATERIAL
BAYS
OFF SHORE OCEAN
DEEP OCEAN
BEACH NOURISHMENT
BEACH FACILITIES
WETLANDS
UPLAND SITES
INLAND FAR FROM SHORE
CHANGE IN CURRENTS TIDES
POT HOLES LARGE AND SMALL
CHANGE IN FLUSHING
CHANGE IN SALINITY LEVEL
CHANGE IN D O H_2S POLLUTANTS
TURBIDITY
SEDIMENTATION
CHANGE TOPOGRAPHY
PRODUCE ISLANDS
RECIRCULATION INTO BAY
NOXIOUS SMELLS
DISPERSAL
CHANGE IN DUNE VEGETATION
DESTRUCTION OF WETLANDS
RUNOFF
SEDIMENTATION
NOTE 1
SALT WATER INTRUSION
IMPROVE NAVIGATION
WATER QUALITY
IMPROVE WATER QUALITY
CHANGE SHELLFISH HABITAT
CHANGE IN FISH HABITAT
ECOLOGICAL SHIFTS
CHANGE SHELLFISH HABITAT
CHANGE BIRD HABITAT
CHANGE IN WATER QUALITY
CHANGE DUNE STABILITY
CHANGE IN SHORE LAND
CHANGE IN HABITAT
CHANGE IN WATER QUALITY
NOTE 1
SHORE RESIDENCE
MARINE INDUSTRY
RECREATIONAL BOATING
SPORT & COMMERCIAL FISHING
COMMERCIAL SHELLFISHING
CONSERVATION GROUPS
RECREATION
NO EFFECT ON LONG ISLAND
RECREATION
SHORE PROTECTION
DEVELOPERS
MOTIVATION
DREDGING PROCESS
CHANGED ENVIRONMENTAL CONDITIONS
HUMAN IMPACT

Figure 7-2. A typical effects linkage shows the disturbance web and environmental impacts of soil removal (from U.S. Department of Interior[10]).

are placed along the center line about midway between the fill bottom and the top of the underlying solid substratum. In addition, at each edge of the fill two or three rows of charges are placed 4 to 5 feet below the surface. The explosion displaces the soft materials, creating a cavity under the fill which then settles rapidly. In the "toe-shooting" technique the soft material is displaced by blasting ahead of the advancing fill. Added fill material is pushed into the cavity left by the blast, and the fill is advanced with a V-point which displaces the soft material and develops a wave in front of the fill. In the process, the front face of the fill is overburdened, and the explosive charges are placed around the toes of the fill near the bottom of the soft material.

The cutting and digging action of the dredging operation breaks through the thin oxidized layer of the submerged soil and exposes the deeper unoxidized layer. Furthermore, most of the sediments placed in suspension are removed from this layer and, hence, are in the chemically reduced state. Such materials have very high chemical and biological oxygen demands. Frankenberg and Westerfield[6] calculated that some dredge spoils require 535 times their own volume of oxygen for complete oxidation, and Brown and Clark[3] reported oxygen levels near dredges 18-83 percent below normal. Both the sedimentary particles and the interstitial waters released contain immediately toxic materials such as hydrogen sulfide, methane, and a variety of organic acids, ketones, aldehydes, etc., as well as heavy metals and pesticides which exhibit persistent toxic effects. Turbidity, per se, reduces light penetration and interferes with photosynthetic production of oxygen, and it tends to elevate water temperatures. Eventually the suspended material settles to the bottom either near the dredging site or far downstream. Thus, there is a redistribution of sediments together with whatever nutrients and chemical pollutants which they may contain, and this may result in modified bottom topography and altered patterns of water circulation. Such sedimentation problems are greatly accentuated when dredge spoil is placed back into the water. General and immediate effects of dredging and spoil placement are listed in Table 7-3.

In coastal marshes the matter is complex because of the adjacency of saltwater and the natural process of coastal subsidence. Coastal marshes, in the undisturbed state, represent vast drainage systems. Freshwater enters on one side, generally from the floodwaters of annual river overflow, and it gradually works down to the coast in a broad, flat surface sheet. Occasional creeks and bayous aid in the runoff. Near the estuaries the marshes are dissected by

Table 7-3. Effects of denuding and/or soil removal on physical and chemical characteristics of marshlands (modified from U.S. Environmental Protection Agency[11]).

Physical and chemical effects	Denuding and soil removal				
	Clearing and grubbing	Soil removal	Rock excavation	Subgrade stabilization	Long term effects
Loss of natural vegetation	X	X			X
Loss of topsoil	X	X			X
Increased surface runoff	X	X		X	X
Lowering of water table	X	X			X
Increased erosion	X	X			
Leaching of soil minerals	X	X			
Violent fluctuation in stream flow	X	X		X	X
Violent fluctuation in water levels	X	X		X	X
Increased downstream flooding	X	X			X
Increased sediment load	X	X	X		
Increased bottom sedimentation	X	X	X		
Loss of wetland habitat	X	X	X		X
Reduction in habitat diversity	X	X	X		X
Increased turbidity	X	X	X		
Changes in water temperature	X	X	X		
Changes in pH	X	X	X		
Changes in chemical composition	X	X	X	X	X
Increased oxygen demand	X	X	X		

dendritic tidal creeks. Thus, through the marsh there is naturally a gradual salinity gradient from freshwater to the more brackish waters of the estuary. Marshes overlie deep layers of unconsolidated river deposits which gradually undergo compaction as the water is squeezed out. Such marshes would gradually subside, but sediment input through river overflow and buildup of organic matter through plant growth counteracts this tendency and maintains the delicate land-sea, and freshwater-saltwater balances.

Soil removal (including denuding) from marshes accelerates the rate of freshwater runoff, and it may lower the water table of the soil, drying out the higher areas of the marsh. Artificially denuded areas do not correspond to natural coastal meandering tidal streams. They may, however, erode to form open canals. Once opened, such canals tend to widen due to tidal and other natural action or due to the effects of boat traffic. Land loss from canal erosion has reached serious proportions in Louisiana and elsewhere.

In addition to draining away the freshwater, the canals offer paths for saltwater penetration of the marshlands, and this is especially prominent in the deeper canals. Since rivers no longer are permitted to flood the upper reaches of the marshes, they are now deprived of both the annual freshwater and the annual sediment load. Thus, as compaction and subsidence proceed, and as saltwater penetrates through the canals, the effect of saltwater is being felt further and further inland. Vehicular traffic over the marshlands (mud-boats, marsh buggies, and heavy equipment) associated with restoration activities accentuates this problem.

Marsh canals have very high contents of organic matter and high oxygen demands. Yet water circulation is often poor, and this leads to reducing or near reducing conditions, especially in the bottom water. Saltwater is rich in sulfates, and when the sulfates enter the reducing conditions, they are converted to sulfides, which are very potent biotoxins. Precipitated iron sulfide is a common marsh deposit.

Spoil banks are often cast up alongside the canals creating a surface dam effect. Such banks impound waters on both sides and seriously interfere with normal surface drainage patterns. The spoil banks directly cover vast acreages of marshland, and erosion from the spoil banks tends to drain back into the canal, on one side, and into the marshland, on the other. Since the sediment itself is mostly in the chemically reduced state, it tends to lower the oxygen concentration of the canal waters when it flows back. Erosion of spoil banks and shallowing of canals require redredging in a never-ending cycle. Effects of soil removal and spoil placement in marshlands are listed in Table 7-4.

Table 7-4. Effects of soil removal and placement of dredge spoil in marshlands (modified from U.S. Environmental Protection Agency[11]).

- Interference with surface drainage patterns
    - Acceleration of surface drainage by canals
    - Damming of surface drainage by spoil banks
    - General acceleration of freshwater runoff
- Loss of marshland habitat
    - Loss due to canalization
    - Loss due to water table lowering
    - Loss due to erosion and widening of canals
    - Loss due to spoil coverage
    - Loss due to acceleration of marsh subsidence
- Acceleration of saltwater penetration
- Conversion of sulfates (of saltwater) to sulfides in the canals and precipitation of iron sulfide in the canals
- Erosion of spoil banks and distribution of chemically reduced sediment into canals and open marsh

7.4 EFFECTS OF CLEAN-UP PROCEDURES ON COASTAL MARSHES

Clean-up procedures considered for marsh land types include temporary containment, contaminant removal and barrier exclusion. The following subsections discuss the effects of these treatments on the marsh ecosystem.

The first techniques considered are those which may be applicable for preventing further spread of contaminants across the marsh until contaminant removal by clean-up can be accomplished. The various alternative methods are considered to be appropriate for coastal marshes if they might prevent further redistribution. The techniques discussed in this subsection include chemical stabilization, clear cutting, stumping and grubbing, plowing, and application of uncontaminated soil cover.

(1-1) Chemical Stabilization

Chemical stabilizers are materials employed to bind soil particles together as an aid to preventing erosion. Chemicals may also be applied to mulch materials to act as a binding agent.

The effect of chemical stabilizers is usually temporary and in the waterlogged soils of the marsh environment may be very transitory. Because of this characteristic, chemical stabilization may not be an appropriate treatment for large areas. However, for small plots, this approach may be of some use. Since chemical application is commonly a part of revegetation programs, little ecological impact would be expected from application in marsh areas.

Certain chemical stabilizers are designed to reduce the rate of infiltration. In a coastal marsh environment, with the frequent flooding associated with high tides, infiltration reduction has little meaning. Use of this treatment is therefore inappropriate for this land type.

(1-2) Clear Cutting Vegetation

Clear cutting would be an appropriate treatment for relatively upland portions of coastal marshes which support significant populations of trees and to large emergent stands such as found in mangrove swamps. Since root systems would not be removed, erosion potential will clearly be appreciably diminished relative to root layer removal techniques discussed in subsequent sections. Root and/or stump sprouting is likely to occur and recovery would thus be accelerated relative to total clearing treatments.

(1-3) Stumping and Grubbing

Stumping and grubbing involves the removal of all surface vegetation and major root systems. Disposal of vegetation may be by natural decomposition or by burning, depending on the volume of organic material and the properties of the contaminant.

The clearing of the land removes the vegetative cover and permits the rainfall to strike the bare land surface. These processes lead to increased surface runoff and severe erosion. The effects will be accentuated in rainy weather. In dry weather considerable quantities of soil in relatively upland areas may be raised as dust clods which will be transported at a later date when the rains fall. Runoff and erosion will add a great deal of soil solids to the marsh resulting in greater water turbidity and increased sedimentation in tidal creeks.

Denuded areas have been shown to lose large quantities of dissolved minerals, particularly sodium, potassium, calcium, magnesium, nitrates, and phosphates. In some cases increased groundwater and springflow has been noted immediately following removal of phreatophytes (which normally pump water up through the roots to be lost via transpiration), but the springflow may eventually diminish as the water table is lowered through lack of recharge.

If the brush cleared from the land is burned in the flood plain the ashes, which are highly alkaline, may enter tidal creeks and cause an immediate increase in the pH of the water (in one study the pH jumped almost immediately from 7.8 to 11.3 and remained high for some time). In addition, heat from the fire can elevate the marsh water temperature quickly and keep it high for some hours.

Denuding equipment in operation as well as spills in maintenance yards can result in the passage of petroleum products into the water courses.

The net result may be summarized in the following points:

- loss of habitat from devegetation of the area
- loss of land fertility from surface erosion and subsurface flow
- increased erosion from denuding site activities
- lowered groundwater level from devegetation
- greatly increased fluctuation in water level due to faster runoff following rains and decreased flow during dry periods because of loss of groundwater
- greatly increased marsh sediment load due to erosion and runoff
- greatly increased marsh turbidity due to erosion and runoff

- modified chemical composition of the water due to increased sedimentation and runoff, turbidity, leaching of soil nutrients.

As a result of these influences, the coastal marsh will undergo a number of changes. The violent fluctuation in water level will result in greater freshwater flow rate during wet weather. The creek beds may be cut deeper, the banks will be undercut, and the open water sections will be widened. Riffles may disappear and pool areas fill. Marsh areas may be swept clear by flood waters.

Increased sediment loads clog the interstices of riffles, fill the pools, and cover the bottom generally with a layer of inorganic silt. Bottom habitat diversity would be significantly diminished. Accompanying the increased runoff, there would be an increase in water turbidity. This lowers the light penetration of the water, increases oxygen demand, and modifies the chemical characteristics of the water in other ways. Loss of vegetative cover and increase in turbidity both serve to elevate the temperature of the water (as much as 10°F).[5]

During dry weather freshwater flow may slack off or it may cease entirely, since the marsh now receives less groundwater inflow than before. As pointed out by Bayly and Williams,[1] land clearing may so alter the local hydrological regime that formerly perennial streams may approach or become intermittent. Since open water pools tend to be reduced or lost, the aquatic habitat may become severely restricted or dried up between floods. Any water that remains is now subjected to more rapid and estreme temperature fluctuation in response to prevailing atmospheric conditions.

The long-term results will depend greatly upon local circumstances but, in general, they would include the following:

- permanent loss of natural land habitat – If the topsoil is eroded away, a native ecosystem will not return for many years
- increased surface runoff and reduced groundwater flow – The denuded surfaces will continue to yield rapid and complete runoff
- persistent chemical changes – The high level of sedimentation and turbidity may eventually taper off.

Recovery after stumping and grubbing would be dependent upon several factors including

- size of area denuded (the magnitude of the effects outlined above would be increased with increasing area)
- location of disturbed area relative to open water (areas adjacent to open water would be subject to runoff effects as well as the erosional influence of tidal currents and wave action)
- weather following cleanup (heavy rains would magnify runoff impacts and extended dry periods would delay recovery by possibly drying exposed muds).

(1-4) Scraping and Grading

Surface alteration such as scraping and grading of a marsh area would have environmental consequences similar to those discussed above for vegetation removal. However, more complete removal of the surface layer organic matter would result with this type of treatment. In addition, epibenthic and burrowing animals would be more directly affected by surface alteration.

Because of the relatively flat characteristics of marsh lands, grading for containment would not entail leveling as may be the case in more upland ecosystems. Grading in coastal marshlands would probably include banking of materials so that drainage patterns would be from the edges of the affected area inward (the reverse of the normal drainage pattern). This could alter the fresh - salt water gradients within the marsh and ultimately modify the biological character of the marsh. However, the slight gradients involved here would undoubtedly be overcome by tidal and wave action and flood events and eventually more-or-less normal gradients would prevail and containment would be temporary.

(1-5) Shallow Plowing

Plowing is not felt to be an appropriate treatment for a coastal marsh. Bottom sediments in marshes are continually in a state of flux in response to tides, waves and runoff events. Plowing would be not only destructive to the marsh habitat but would also probably enhance contaminant mobility by disrupting the hydrologic regime and creating new flow routes.

(1-6) Deep Plowing

See treatment 1-5; this technique is not appropriate for this land type.

(1-7) Soil Cover Less than 25 cm

Because of the scouring action of tides, waves and flood events, thin soil cover may be only a very temporary containment treatment for this land type. Thus its use in marsh systems may be limited.

The effects of this treatment are in two areas—the area covered and the source of the cover material. Naturally the magnitude of effects, and hence the restrictions to recovery are a direct function of the area treated.

In the covered area, the habitat of epibenthic, burrowing and semi-terrestrial animals would be destroyed. Also young stands of marsh grasses would be buried and would not be expected to survive. Larger grasses, bushes and trees would not be buried; however machinery used to dump the cover soil may be very destructive.

Recovery would be more rapid than if the covering process was preceded by vegetation removal, as root or stem sprouting may not be prevented with the shallow cover. Vegetation recovery would be fairly rapid with this treatment due to the shallowness of the cover which would not bury larger plants and which would probably soon erode.

(1-8) Soil Cover 25 to 100 cm

If the uncontaminated soil fill is up to 100 cm in depth, then the marsh has simply been filled in and it no longer can be referred to as a coastal marsh. The addition of 100 cm of soil may cause the land level to excbed the tidal ranges and, consequently, the saltwater intrusion which is characteristic of a coastal marsh will cease to occur. The marsh may: (1) cease to have a hydric soil and begin to behave as a predominantly non-hydric type; (2) change from a vegetation cover of hydrophytes to predominantly mesophytes or xerophytes; (3) change from land that is flooded at some time of the year to land that is infrequently or never flooded during years of normal precipitation.

Treatments considered next are those which remove contaminated soil layers. Mechanical and chemical stabilization after soil removal is also discussed.

(2-1) Remove Plow Layer

The plow layer is defined here as the soil layer from the surface to a depth of about 10 centimeters. Removal would be accomplished by hand shovelling or larger digging machinery. The unstable marsh soils would necessitate working from platforms, barges or other support structures.

The ecological effects of soil removal in the marsh would be similar to those discussed for surface alteration (scraping and grading) and vegetation removal. Some inference can also be drawn from the earlier discussion of dredging effects (Section III). Major influences include

- acceleration of surface runoff
- alteration of drainage patterns
- loss of habitat for wildlife
- increased erosion
- loss of organic matter and nutrients in surface soil layers.

Recovery would be similar to that for scraping and grading but would be slower because more of the soil-organic layer is removed and elevations are somewhat altered thus changing the tidal flooding depth.

(2-2) Remove Shallow Root Zone

In a coastal marsh, the root zone is relatively shallow and therefore, the effect of soil removal to the depth of a plow layer and/or to the shallow root zone can be treated the same. See treatment 2-1.

(2-3) Remove by Scraping and Grading, Mechanically Stabilize

The effects of scraping and grading are discussed in treatment 1-4. This treatment, combined with "mechanical stabilization" includes removal of contaminated soils (less than 5 cm in this case) and compaction of subsurface soils or surfacing with impervious materials to seal the subsurface against infiltration. As previously noted (treatment 1-1) infiltration control in a marsh area which is at least periodically flooded has little meaning. Hence this combined treatment method is inappropriate since mechanical stabilization is inappropriate.

(2-4) Remove Plow Layer, Mechanically Stabilize

This combined treatment is inappropriate for the marshland type; see treatment 2-3 and 2-1 for further discussion.

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

This combined treatment is inappropriate for the marshland type; see treatments 2-3 and 2-2 for further discussion.

(2-6) Remove by Scraping and Grading, Chemically Stabilize

The effects of this combined treatment are essentially those discussed in treatments 2-3 and 1-1. The chemical stabilization method employed would have to be instituted for erosion control rather than infiltration control for the reasons previously given. The erosion control provided would be expected to be transient but might be sufficient to somewhat mitigate runoff impacts resulting in a more rapid recovery than scraping and grading alone.

(2-7) Remove Plow Layer, Chemically Stabilize

This combined treatment would result in effects similar to those discussed for plow layer removal alone (treatment 2-1). However, as discussed above, erosional problems would be mitigated temporarily and recovery would be somewhat more rapid than that without stabilization.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

The effects of this treatment are discussed in treatments 2-2 and 2-7.

Barriers to exclude people and to exclude both large and small animals are discussed in the following treatments.

(3-1) Barriers to Exclude People

It is assumed that exclusion would be accompanied through the use of barbed wire fencing or some sort of mesh material such as chain link or Cyclone fencing, hardware cloth, or poultry wire.

If a natural state is deemed beneficial, then nothing but benefit can derive from the exclusion of humans. Benefits due to increased "naturalism" will accrue in direct proportion to the intensity of previous human use or intrusion. Numbers of species and their diversity will certainly increase as shy species return to the marsh; this may be especially true in the case of migratory game fowl if hunting is terminated. Vegetative cover, and hence primary and secondary productivity, will increase if these parameters had been below maximum levels due to human trampling. However, note that secondary productivity is not likely to increase greatly due to the lack of macrophyte-consuming herbivores which frequent salt marshes. Finally, erodibility would likely remain unchanged or perhaps even decrease; indeed, a negative erodibility may exist for marshes since they are areas of deposition.

Humans often find cause for interfering in coastal marshes, especially when they live near such areas. Natural marshes are doomed to self-destruction due to sedimentation and consequent evolution (succession) into an upland habitat. Part of this evolution is often the buildup of a bar at the tidal inlet(s), hence, the tidal flushing of the marsh is greatly reduced or eliminated. As this happens, conditions may become anaerobic as water temperature and salinity rises and, therefore, marsh flora and fauna die and decay. Such conditions create a great nuisance near points of human activity, and they provide a haven for insects such as gnats and mosquitoes, further aggravating the condition of local human populations. For exactly these reasons, and also to maintain a maximum level of productivity, marsh channels are often dredged regularly, especially at the tidal inlet(s).[4] Such dredging also enhances the flood control value of marshlands by providing open channels for runoff during precipitation events. Thus, exclusion of human activity may not be taken to include channel dredging, especially if there is significant human activity in the vicinity of the contaminated area. It should be noted that, if periodic dredging is performed, the dredged materials must be checked for contaminant level and, if found to contain unacceptable levels of contamination, must be dealt with accordingly.

(3-2) Barriers to Exclude Large Animals

Not applicable to this land type.

(3-3) Barriers to Exclude Large and Small Animals

It is assumed that exclusion would be accomplished through the use of fine-meshed materials, such as screen with mesh diameter less than 1.0 cm, or through the use of solid materials, for example, brick and cinder block.

Animals such as mice, voles, raccoons, rabbits, possums, skunks, weasels, and coyotes could be excluded by this treatment.[4] Mammals rarely live within a coastal marsh; generally they reside in nearby upland habitat and use the marsh only for forage, consuming seeds, some plants, insects, and other small animals. Further, such mammals are noted to be "represented by relatively small populations." Hence, exclusion of these creatures would have very little effect on the marsh ecosystem; a slight drop in species diversity and in the total number of species occurring in the marsh would be the only noteworthy effects.

However, if a large area, e.g. 1 to 10 km^2, were fenced off, the resulting pressure on surrounding lands for forage and prey could cause significant harm to these lands. This also could cause effects on nearby human populations ranging from a minor nuisance to a significant economic hardship, for example, if the search for food led the displaced animals into human dwellings or into agricultural lands, of if predators were forced to prey upon domestic animals.

Birds are the most important small animals in a coastal marshland from the perspective of contaminant mobility. Birds forage on seeds, benthic invertebrates, open channel vertebrates, and insects; some of these prey species may concentrate a contaminant through direct ingestion (e.g., worms and filter feeders), or through their own food source which has already ingested a contaminant and perhaps concentrated it to some degree. Hence the birds may ingest significant quantities of a contaminant and may then pass it through their digestive system and deposit it offsite in feces or concentrate the contaminant in their own tissues and then die or be preyed upon offsite. The former seems more probable. The same set of circumstances may also apply to fish and insects, in which cases the latter event is more likely.

Therefore it may be pointless to prohibit only horizontal crossings at the land surface; some sort of barrier to movements above and below the surface may also be desirable. The effects of such barriers would be considerable, compounding greatly as the size of the area of exclusion increases.

First, although net secondary productivity may change very little over a long period of time, large short-term fluctuations may be expected as predator species and prey species adjust to sudden partitioning from each other. It is especially the prey species which may explode in population with a sudden halt to predation. "Boom and bust" cycles of prey populations could be expected as the affected species increase their numbers, outstrip the available food supply, and die back in catastrophic instances, whereupon the cycle is renewed. It can be seen that, within this cycle, vast effects on the food sources of the former prey species can be expected.

Additional effects can be anticipated from the elimination of certain species which spawn in the marshland. These effects may range from the trivial to the extreme depending on the size of the area fenced from the intrusion, the availability of alternative breeding sites, and the importance of the species whose spawning grounds have been contaminated.

Additional pressure on surrounding lands from avian predators and foragers displaced from the contaminated areas can be highly significant if surrounding marshland is burdened beyond its capacity to produce food for the displaced birds. This could occur, for example, if half of a 20 km^2 marsh were fenced and screened. Thus, wildly fluctuating populations of predator, prey, and forage species may occur offsite in areas unaffected by contamination.

Finally, diversion of migratory waterfowl from contaminated marshlands can not only have serious effects on surrounding areas, but may also irrevocably reduce the populations of sensitive species already pressured by general habitat reduction, diversion from nesting or wintering sites by human activities other than habitat reduction, and hunting. Such effects would be entirely site-specific and cannot be addressed further for the general case.

(4-1) Asphalt Hard Surface Stabilization

This treatment is outside the scope of work.

(4-2) Concrete Hard Surface Stabilization

This treatment is outside the scope of work.

(5-0) Application of Sewage Sludge

This treatment is outside the scope of work.

(6-1) High Presure Washing (<3 cm)

This treatment is outside the scope of work.

(6-2) Flooding to 30 cm

This treatment is outside the scope of work.

(7-0) Soil Amendments Added

This treatment is outside the scope of work.

7.5 RECOVERY AFTER CLEANUP

Recovery of coastal marsh ecosystems following clean-up operations is dependent upon several factors beyond the characteristics of the clean-up operation itself. Included in these factors are

- the size of the area affected by the clean-up operation
- location of the disturbed area relative to open water (areas adjacent to open water are subject to wave and tidal effects as well as fresh water runoff)
- weather conditions following cleanup (heavy rains would increase runoff erosion problems)

The sequence of events leading to "complete" recovery in a coastal marsh system is not a multistep successional scheme such as is the case with development of the classic climax forest. Recovery in the marsh system would be essentially directly from disturbed state (e.g. denuded) to the original vegetation type (e.g., Spartina). Graphs portraying a very general recovery sequence are provided in Figures 7-3 through 7-5 (see Appendix B).

The rate of recovery is largely determined by the erosional processes which characterize the marsh system and which may be intensified by cleanup. The growth rate of vegetation is probably secondary to the physical processes determining soil stability and substrate composition. With the normal high productivity rates characteristic of the marsh land type, once erosion is controlled and revegetation initiated, recovery would be expected to proceed quite rapidly.

7.6 QUANTITATIVE ASSESSMENT OF CLEAN-UP IMPACTS

Clean-up procedures in coastal marshes are scaled in Table 7-5 with regard to impact on this ecosystem. The scaling provides a relative view of the length of time (in growing seasons) required for complete recovery to the

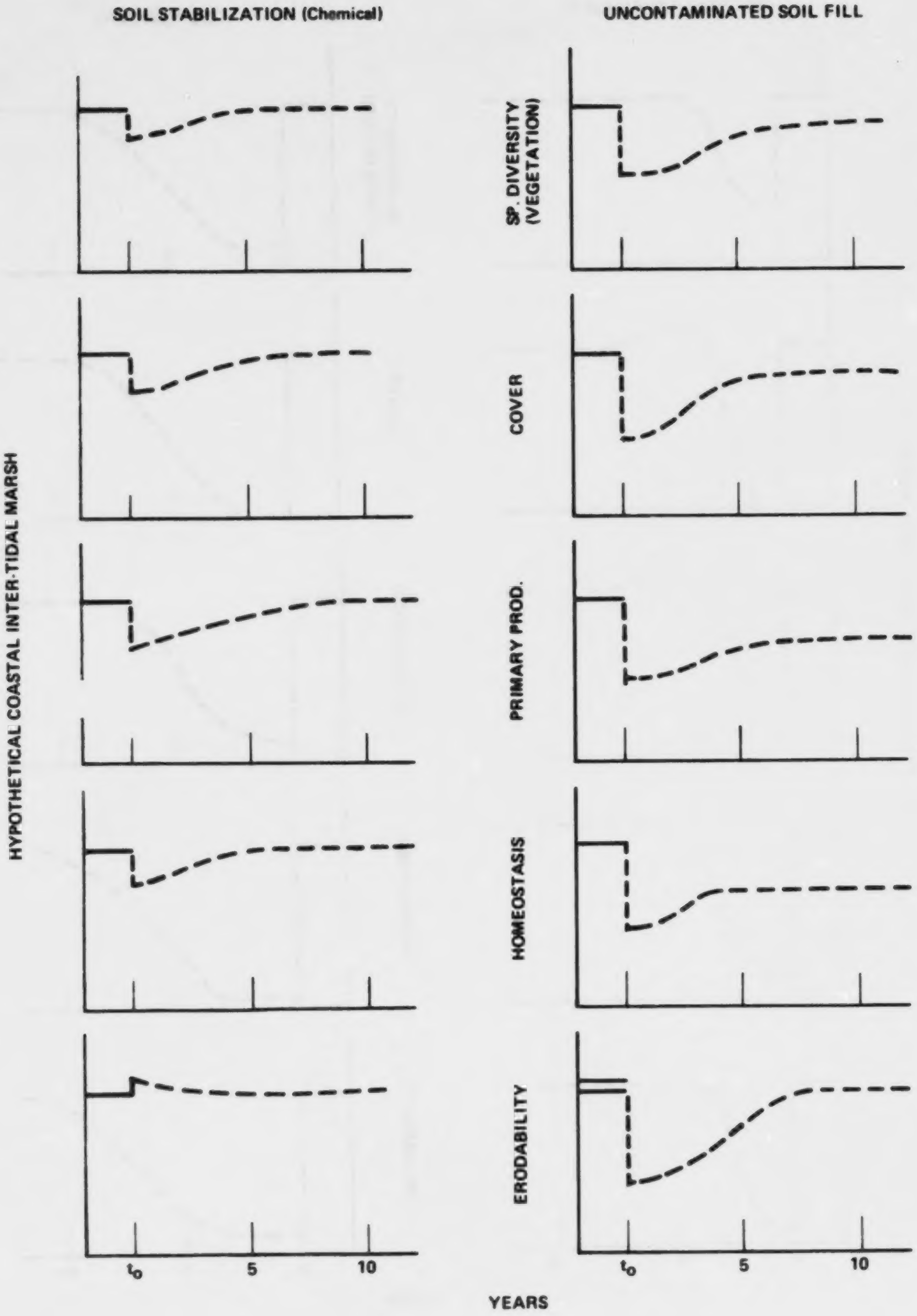

Figure 7-3. Recovery of coastal inter-tidal marsh following chemical soil stabilization and application of shallow soil cover.

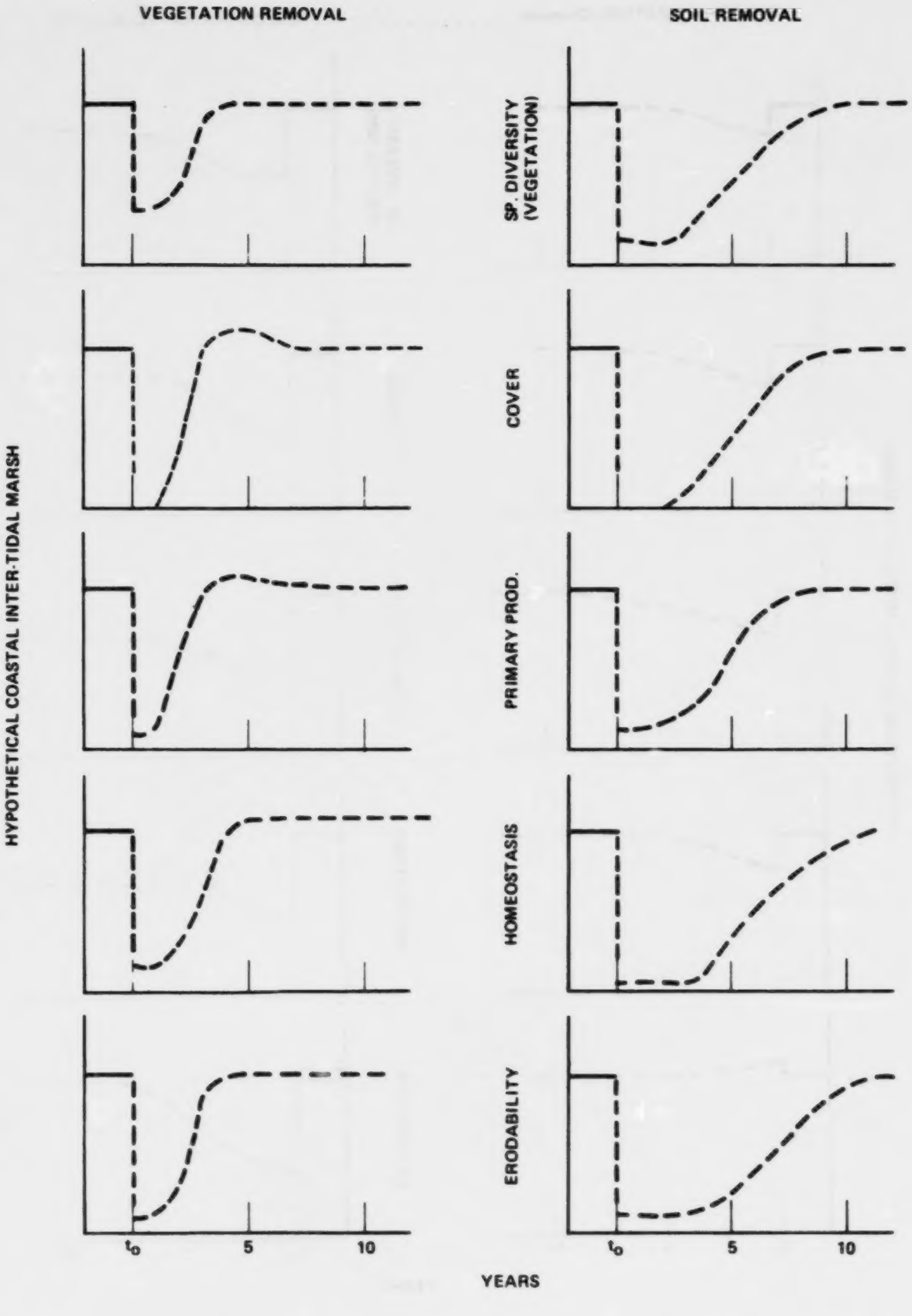

Figure 7-4. Recovery of coastal inter-tidal marsh following vegetation removal and shallow layer soil removal.

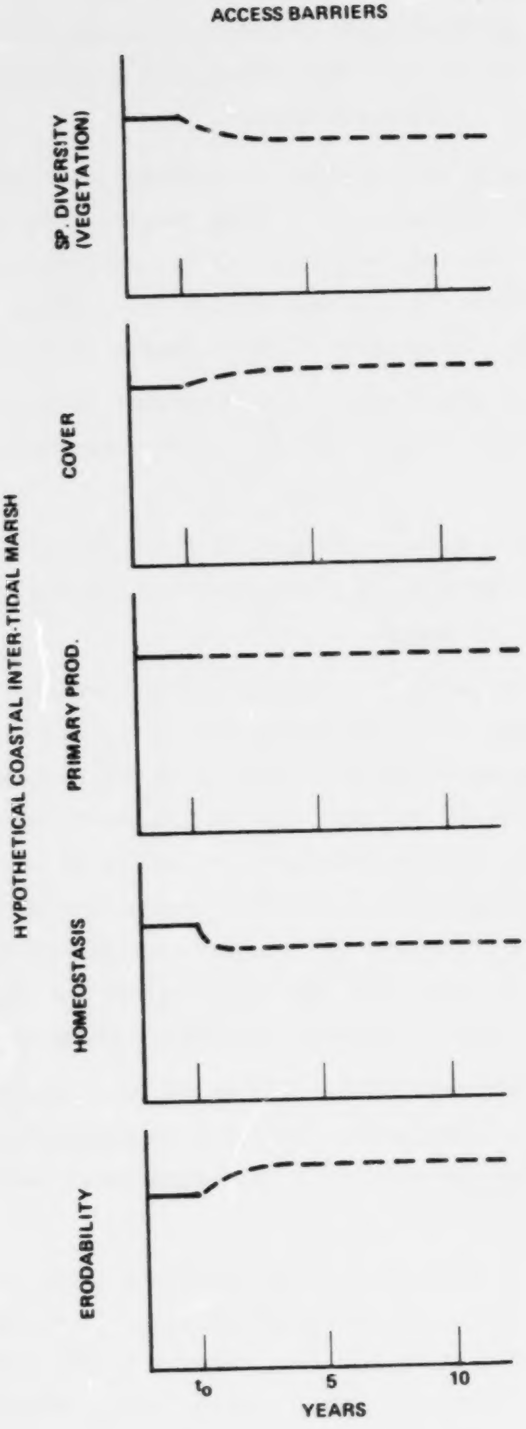

Figure 7-5. Response of coastal inter-tidal marsh to the erection of fencing.

"natural" state after clean-up operations are terminated. It should be stressed that these rankings are highly subjective in nature. The speculative nature of these results is also emphasized by the location and meteorological factors which will influence recovery.

The confidence with which this scaling is provided is somewhat inversely related to the size of the area affected. This results from the uncertainties related to recovery processes and the potential for external influences on the marsh ecosystem subsequent to clean-up operations. Hence the scaling here is much more relative than absolute (more numerical than quantitative).

The rationale for developing Table 7-5 is provided in Section 7.4. General conclusions drawn from Section 7.4 and Table 7.5 are presented in the following section.

Examination of Table 7-5 indicates that for the 0.01 km^2 area, the treatments may be grouped into three basic categories with regard to level of effect and length of time to recovery.

The lowest impact group includes construction of barriers (3-1, 3-2), chemical stabilization alone (1-1), clear cutting (1-2) and soil covering (1-7, 1-8). The common characteristic of this group of treatments is generally a lack of disturbance of the root and "native soil" structure. Organic muds and root systems may mitigate erosion, which is an important factor in recovery of the coastal marsh. Naturally, some disruption will occur from the means and equipment involved in the clean-up operations. Hence, barrier construction (3-1, 3-2) will have the least impact and soil covering (1-7, 1-8) the most within this relatively low impact group of treatments.

Deep soil coverings (1-8) may elevate the marsh to a level where the natural flooding cycles are eliminated. Recovery in such areas would not lead to a marsh habitat, but creation of a new terrestrial habitat within the coastal marsh.

The group of treatments which have an intermediate level of effect includes surface alteration (scraping and grading) alone (1-4) or accompanied by chemical stabilization (2-6); stump and root removal (1-3); and removal of the plow layer followed by chemical stabilization (2-7). These clean-up treatments are characterized by a more severe disruption of the native soil

Table 7-5. Predicted years to reestablish precleanup marshes.

Treatment	Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	0	0	0	0	
1-1 Chemical Stabilization	0	0	NA	NA	
1-2 Remove Vegetation by Clear Cutting	5	5	10	15	In upland or mangrove areas
1-3 Remove Stumps and Grub Roots	10	10	15	20	
1-4 Surface Scraping and Grading (<5 cm)	10	10	15	25	
1-5 Shallow Plowing (<10 cm)	NA	NA	NA	NA	
1-6 Deep Plowing (10 to 40 cm)	NA	NA	NA	NA	
1-7 Soil Cover (<25 cm)	5	7	12	18	
1-8 Soil Burial (25 to 100 cm)	5	10	20	30	Marsh elimination possible
2-1 Remove Plow Layer Soil (10 cm)	12	15	20	30	
2-2 Remove Shallow Root Zone Soil (<40 cm)	15	20	25	35	
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	NA	NA	NA	NA	Mechanical stabilization inappropriate for marshland type
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	NA	NA	NA	NA	
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	NA	NA	NA	NA	
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	7	8	15	15	Chemical stabilization may not be appropriate for large areas
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	10	12	20	30	
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	12	15	25	35	
3-1 Barriers to Exclude People	0	0	0	0	
3-2 Barriers to Exclude Large Animals	0	0	0	0	
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	
4-1 Asphalt Hard-Surface Stabilization	*	*	*	*	
4-2 Concrete Hard-Surface Stabilization	*	*	*	*	
5-0 Sewage Sludge Application	*	*	*	*	
6-1 Washing (<3 mm)	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	
7-0 Soil Amendments Added	*	*	*	*	

*Outside scope of work.

NA - not appropriate for this land type.

structure than would be experienced with the lowest impact group. Thus the potential for erosion is more substantial and recovery would be delayed as a result.

In addition to increasing erosion, removal of roots and disruption or removal of surface soils would remove the plant and soil materials which would most enhance rapid habitat recovery. Root sprouting, which would occur after clearcutting (1-2) would be eliminated and revegetation would occur via root systems in adjacent areas and seeds dispersed by wind and flooding of the area. Revegetation by seeds would be hindered to some extent by surface disruption and soil removal.

The most deleterious set of clean-up treatments include removal of the plow layer (2-1) and removal of the shallow root zone (2-2). The processes of increased erosion and delayed revegetation, which are discussed above, are enlarged by these treatments.

As previously stated, the level of effect associated with any of the treatments for the marsh land type is area dependent. That is, the effects generally increase with size of the area affected. This dependence can be clearly seen from the importance of erosion in determining recovery and the importance of neighboring areas for revegetation. With the smaller sized clean-up areas, the surrounding area would act as a buffer for both tidal and freshwater flooding events. In addition, seeding and root sprouting from adjacent areas would be more effective with smaller cleared zones. Larger clean-up sites would benefit less from these erosion buffer and revegetation processes, and hence slower natural recovery would be expected.

Treatments which do not involve disturbing the spill area (i.e. natural rehabilitation (0-1) and barrier construction (3-1, 3-2) would not have area dependent impacts. However, some increased stress in adjoining areas may result with increasing size of barrier enclosures.

As discussed in the preceding sections several of the alternative clean-up treatments may effectively destroy the marsh land type. In these instances, recovery would not be to the original habitat form. Such treatments include 2-2, removal of the shallow root zone (less than 40 cm), and 1-8, deep soil covering (up to 100 cm). The flooding cycle may be disrupted to the extent that the former treatment results in an open water area and the latter in a more dryland environment. Because of these consequences, these treatment types may not be reasonable with regard to recovery considerations. The effects of other treatments are probably not irreversible although subsequent erosional damage may result in an extended recovery period, particularly for larger treatment areas.

7.7 CONCLUSIONS

Of the clean-up treatments considered, several were concluded to be inappropriate for the coastal marshland type. Shallow and deep plowing is not appropriate for containment of spill materials. Mobility would be enhanced rather than retarded by this action. Also, mechanical stabilization is inappropriate as a mechanism for sealing the marsh soils against infiltration. This is because infiltration control has no clear meaning for a frequently flooded environment such as a marsh. For similar reasons, some chemical stabilizers are inappropriate treatments in coastal marshes. However, for binding soil materials together to mitigate erosion, chemical treatments may be useful as a temporary measure, particularly for rather small disturbed areas.

Soil removal methods were concluded to be the most deleterious to marsh recovery. Effects of such treatment increases with the depth of removal. Deep soil coverings may have similar effects. In fact, appreciable elevation alterations in either direction may effectively destroy the marsh habitat; recovery may be to more terrestrial or to open-water communities. Chemical stabilization may mitigate erosion and thus aid recovery for all soil removal techniques from scraping and grading to removal of the shallow root zone. Vegetation removal was felt to be less destructive than soil removal treatments since the substrate materials which supported "climax" vegetation may remain largely undisturbed. Clear cutting is certainly less detrimental than removal of all vegetation and roots.

Barriers were felt to have little overall effect on the coastal marsh although certain stresses in neighboring areas may result.

7.8 COASTAL INTER-TIDAL MARSH REFERENCES

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PART II

MANAGED ECOSYSTEMS

CHAPTER 8, AGRICULTURAL LAND AREAS
CHAPTER 9, URBAN/SUBURBAN LAND AREAS

CHAPTER 8
AGRICULTURE

8.1 OVERVIEW

Lands used for the production of renewable resources and products consumed as food, fiber, timber, and feeds for livestock are by definition agricultural lands. Crops raised for livestock feeds are discussed as forage, permanent pasture, rangeland and the native pastures of woodlots. Plant species discussed range from local area natives to patented specialty cultivar crops.

In the broad sense, agricultural land could include tundra crops of lichens consumed by reindeer herds and the alpine meadows grazed by rodent herbivores. A narrower view is held in this chapter. Agricultural lands are considered to be those managed to produce crops at commercially significant rates for food, feeds, and fibers.

In this chapter the impacts by cleanup are taken as short-term disturbances because the vegetative component can be replaced precisely—for a price. Mature deciduous trees as large as 20 to 23 cm in diameter and 8 meters tall can be dug up, moved, and replanted in normal landscaping.[10] Sodding or reseeding is likewise economically determined as are most decisions about rehabilitation of agricultural lands after cleanup of some contaminant. As a routine practice in the deciduous forest, a farm can be cleared of standing crops, whether small grains or timbered woodlot, surface-mined for coal, the spoils graded to the original contour, limed, fertilized, reseeded, and be back in full production in 2 years. Equipment used in surface mining is different from earthmoving equipment for local road building, light building construction and farming. In general, surface-mining earthmoving equipment is orders of magnitude larger than usual construction equipment.

Agricultural land is estimated to be from 526 million hectares to 930 million hectares in the United States[5] but a variety of figures are used for agriculture depending on the author's interest. The percentages of use are approximately 25 percent for grazing in livestock production and 20 percent for crop production.

This chapter concentrates on farming in three of the natural ecosystems. These are the hot desert of the southwestern United States, where irrigation supplies almost all agricultural water supply, the adjoining midcontinental grasslands, and the formerly hardwood forest areas. These are located as defined in Figure 8-1. Because it lies in the intermediate position between the other two sources of agricultural land, and because almost the entire grassland has been appropriated for agriculture, the prairie is described in some detail with its crops. The irrigated desert is confined to gently sloping or flat terrain and the actual commercial use is a small portion of the desert terrain. Deciduous hardwoods occupy rolling to steeply sloping terrain but agriculture is practiced on the flatter slopes which, as in desert, are only a fraction of the total area.

Agriculturally important, the midcontinental grasslands in Figure 8-1 reach from the 30th parallel in the south to the north beyond the Canadian border. Bordered on the west by the Rocky Mountains, they rise along the 105th meridian from the central Mexican border into Wyoming, turning northwestly across 8 degrees of longitude before meeting the Canadian border. The eastern grasslands boundary lies along the 96th meridian with a major incursion, generally northeast on a concave arc, from the Red River into south central Ohio. The east grassland boundary keeps west of the Mississippi River to the Missouri River, crosses both in a few miles and arches north of the Ohio River into central Ohio, north across Ohio, and turns generally west to recross the Mississippi and parallel it to the northwest, crossing into Canada on the 96th meridian.

Topography of the agricultural prairie ranges from the western short grass high terraces and alluvial fans across the plains to the steep hills and lakes on the eastern fringes of Illinois and west Ohio. The wide, level to gently rolling plains with tree-clad streambanks in the prairie midsection were the first to fall totally to the plow as croplands. Hard red winter wheats grow in the southern prairie and grade into hard spring wheats in upper Nebraska north to the Canadian border.[13] Annual precipitation in the winter wheat belt ranges from 350 mm in eastern Colorado, Wyoming, and Montana to

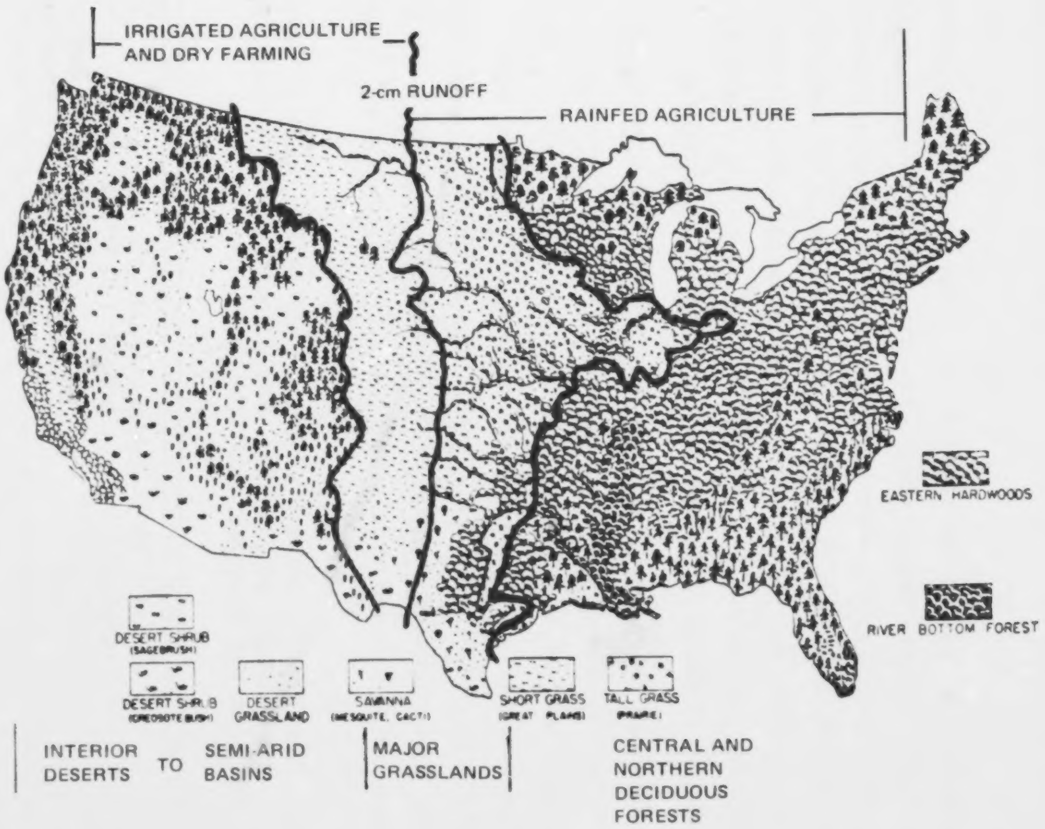

IRRIGATED AGRICULTURE AND DRY FARMING
2-cm RUNOFF
RAINFED AGRICULTURE
EASTERN HARDWOODS
RIVER BOTTOM FOREST
DESERT SHRUB (SAGEBRUSH)
DESERT SHRUB (CREOSOTE BUSH)
DESERT GRASSLAND
SAVANNA (MESQUITE, CACTI)
SHORT GRASS (GREAT PLAINS)
TALL GRASS (PRAIRIE)
INTERIOR DESERTS TO SEMI-ARID BASINS
MAJOR GRASSLANDS
CENTRAL AND NORTHERN DECIDUOUS FORESTS

Figure 8-1. Indigenous vegetation zones of the conterminous United States (adapted from Shantz and Zon[15]).

900 mm in eastern Kansas and Oklahoma, with warmer summers and longer growing seasons than the spring wheat belt. Precipitation in the spring wheat belt ranges from 300 mm in northern Montana to 600 mm in western Minnesota and eastern Dakotas. Generally, the separation of the winter and spring red wheats is the isotherm of 18°C for the three summer months of growth into ripeness.

Precipitation regimes for prairie are shown in Chapter 2, Part I, and these are basic figures around which agricultural needs are managed. In the west side near the Little Powder River in northeast Wyoming, annual rainfall is 400 mm with an evaporation potential for 1500 mm in an area where wheat and oat agriculture displaced mixed prairie grassland and artemesia species, but the primary use became cattle-grazing because of the combination of limited rainfall and deficiencies in soil phosphorus and nitrogen.

The physical characteristics of prairie soils reflect the environmental regimes of the grasslands as shown in Table 8-1. On the Missouri side, the soils are deep and the rainfall is sufficient for tall grass. The Colorado side of the prairies have permanently dry subsoil and short grass. Between these boundaries lies the minimum line of annual runoff shown in Figure 8-1 as the 2-cm precipitation isogram. The small grains straddle this precipitation feature and their presence results in the designation of "breadbasket."

Table 8-1. Relationship between annual precipitation, species composition, and moisture consumption, Rocky Mountains to Missouri transect of prairie (adapted from Jenny[12]).

Indigenous Plant Community	Depth to permanently dry zone (cm)	Approximate annual pptn (cm)	Plant height (cm)	Region of observations
Grama grass Buffalo grass	30-36	<45	10-35	Eastern Colorado
Wire grass	60-80	45-55	45	Western Kansas
Bluestem grass Bunch grass	85-115	55-70	75	Central Kansas
Bluestem grass Sod grass	absent	70-100	110	Eastern Kansas and Western Missouri

8.2 NATURAL PERTURBATIONS

The significant agricultural event in physical and economic terms is the loss of soil by erosion processes.[18] These losses are generated by two different agencies, wind and water runoff. West of the 2-cm isogram (Figure 8-1) erosion is driven by wind. East of the 2-cm isogram water runoff is the principal erosive force.

Publications dealing with erosion are numbered in the thousands. One agency field office has collected 2,500 reports, bulletins, and books on wind erosion alone.[5] This author estimates runoff erosion publications number more than twice as many as cited for wind erosion. A simplification is called for.

The national wind erosion area is defined in Figure 8-2, while water erosion sites are shown in Figure 8-3.

Wind erosion data and its erosive forces are used in general predictions of soil loss as shown in handbooks.[3] However, these must be used with caution. Attempts to estimate wind erosion by land types across the spectrum of suggested cleanup techniques faces a basic inadequacy in the primary data. The data on wind speed and direction are generally collected at airport locations and a few electricity-generating plants. These locations are representative of flat terrain rather than rolling, or hilly or mountainous regions. The erosive power of wind may be seriously underestimated by using published data to predict wind erosion damage for sites as small as 10 km^2 and smaller and a few kilometers distant, since the extreme wind speed is pertinent. Horizontal extrapolation of wind speed for offsite predictions faces directional shear, turbulent discontinuities, and orographic deflection of unknown magnitudes.

Wind-energy distribution maps are being undertaken at this time and may alleviate a degree of the risk in making horizontal extrapolations from the site of measurement to the cleanup site. These maps will be useful in flat terrain under overcast conditions. They are not available for generic use unless the cleanup treatments are restricted to the vicinity of airports.

Probably the best return in deciding what sites should be chosen as candidates for cleanup would come from installing remote wind recording equipment

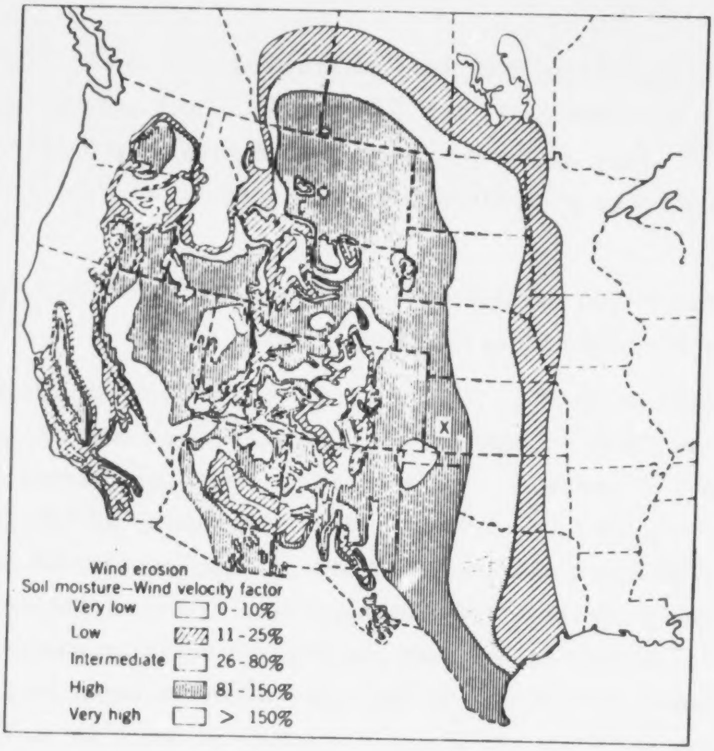
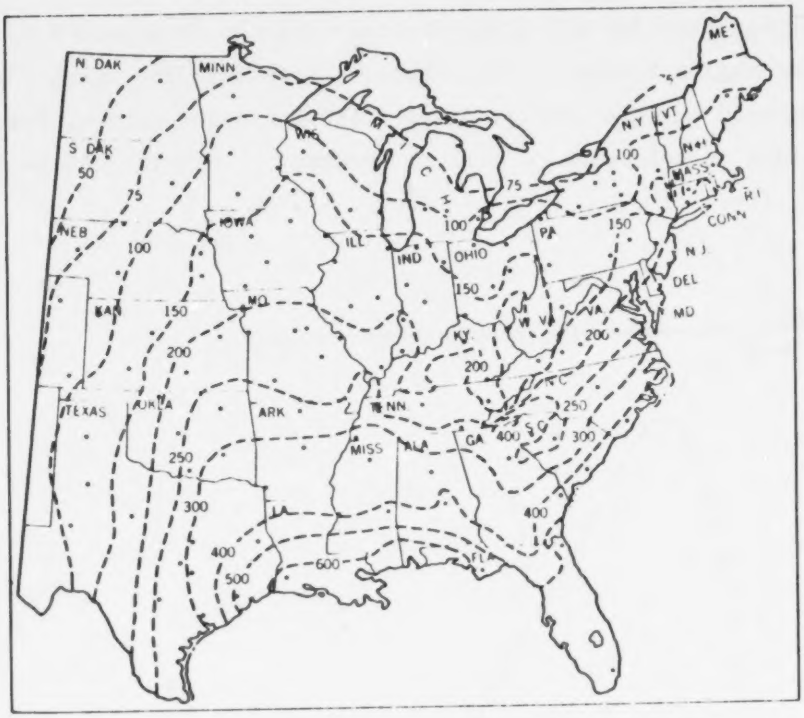

X
Wind erosion
Soil moisture—Wind velocity factor
Very low 0-10%
Low ▨ 11-25%
Intermediate 26-80%
High 81-150%
Very high > 150%

Figure 8-2. Surface soil moisture-wind velocity soil loss factor as a percent of soil loss at Garden City, Kansas (marked by X) (adapted from Agricultural Research Service[2]).


N DAK
MINN
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50
75
NEB
100
IOWA
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MICH
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OHIO
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RI
CONN
ME
NJ
DEL
MD
KAN
150
MO
200
KY
W VA
VA
NC
TEXAS
OKLA
ARK
TENN
250
SC
300
400
GA
MISS
ALA
LA
FLA
500
600
75
100
150
200

Figure 8-3. Rainfall erosivity index, based on maximum 30-minute intensity, from an average of annual maximums (from Wischmeier[17]).

and precipitation recorders at the sites. From onsite data general regressions would be possible with the weather station network data. Without onsite data the predictions are worthless since they can be highly misrepresentative of the site.

Rainfall intensity is the factor detaching soil fragments and allowing runoff to carry them away. The data summarized in Figure 8-3 represent a portion of the work done by Wischmeier and his colleagues. One of their summaries[1] has been widely used in erosion predictions. Two reviews of erosion dislocation mechanisms and of detachment by wind[9] and water[16] lay the basis for the widely used "Universal Rainfall-Erosion Equation." This is based on the kinetic energy of the rainfall and the maximum 30-minute intensity of the storm. It must be used by trained staff for particular sites.

Plant growth, precipitation and climate are interrelated variables that determine the erosive force exerted upon soil from which sediments are derived.

A general integration for all these factors is shown in Figure 8-4. That precipitation regime transects the natural ecosystems upon which the agriculture discussed in this chapter draws. These are the natural forces that test the wisdom in selection of cleanup treatment, when the choice is field-tested at a site.

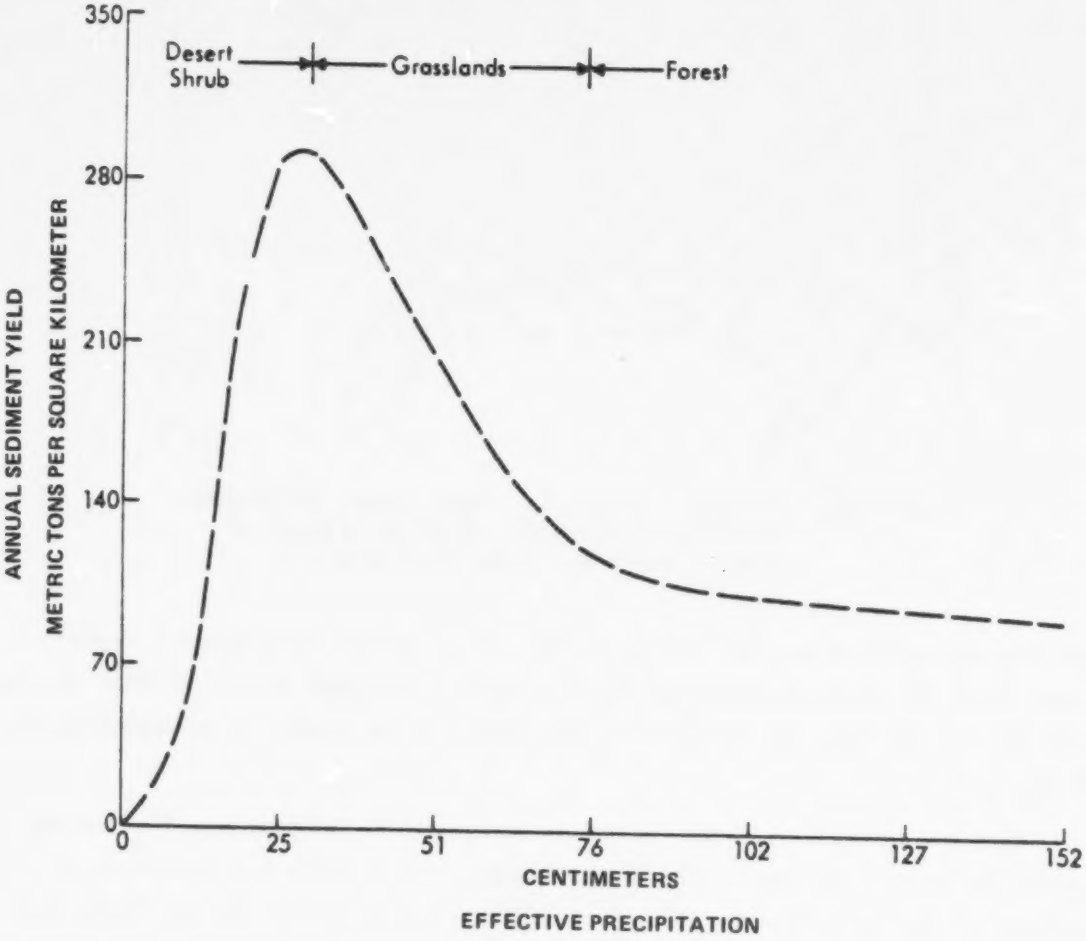

Figure 8-4. Idealized effective precipitation, vegetation, and sediment yield on west to east transect (adapted from Bennett and Donahue[8]).

8.3 MAN-MADE PERTURBATIONS

All agriculture is a man-made perturbation that functions as a production system because of the energy added to change it from a natural ecosystem. In the context of this chapter the alleviation of natural perturbations on cleanup areas is addressed.

The ideal preventative of wind and water erosion is a layer of wetted, attached mulch. For semi-arid lands the procedures were derived after the enormous dust storms of the late 1930s. The amount of mulch needed varies with soil texture and species of crop.[3] A summary of application rates for deciduous forest agriculture is given in Table 8-2. As shown there seedling plants hold soil losses to those comparable to tonnage quantities of straw and stover (fodder) residues. Plant residues and seedling grasses are almost universally used for wind and water erosion control.

Table 8-2. Effectiveness of ground cover on soil erosion loss at construction sites in deciduous forest zones.

Ground cover	Soil loss relative to bare surfaces (percent)
Established seedlings	
Permanent grasses	1
Ryegrass (perennial)	5
Ryegrass (annual)	10
Small grain	5
Millet and sudangrass	5
Field bromegrass	3
Grass sod	1
Hay (5 tons per ha)	2
Small grain straw (5 tons per ha)	2
Corn residues (10 tons per ha)	2
Wood chips (10 tons per ha)	6
Asphalt emulsion (310 gal per ha)	2

(Adapted from Hotes et al.[11])

Large amounts of surface runoff are generated by acreages of cropped soils. Need for runoff control is intensified where the soil is bared and multiple treatments are rated for runoff control in Table 8-3. These are the kinds of combined treatments that are evaluated in Section 8.6, Quantitative Assessments.

Table 8-3. Control systems and relative effectiveness.

System	Components	Percent effectiveness
1.	Seed, fertilizer, straw mulch plus erosion structures, normal	91
	Same as (1) except chemical (12 months protection) replaces straw	90
	Same as (1) except chemical straw tack replaces asphalt	91
2.	Seed, fertilizer, straw mulch with diversion berms plus sediment basins	90
3.	Seed, fertilizer, straw mulch; downstream sediment basin using flocculants	96
	Same as (3) without straw mulch	94
4.	Chemical (12 months protection) sediment basin using flocculants	94
	Same as (4) with seed, fertilizer	96

(Adapted from Hotes et al.[11])

8.3.1 Runoff and Fertilization

Runoff does more than produce sedimentation. It can strip away organic matter and mulches. The plant nutrients lost in this way are some of those recommended for reseeded areas in Table 8-3. These nutrient losses were studied quantitatively on field plots in 1917 and included nitrogen, phosphorus, calcium, and sulfur.[7] A recent review on phosphorus[14] losses from vegetables fertilized with manure placed losses at 70 kg/ha per year.[14] This is much more than many farm programs call for in fertilization regimes. Seasonal variations are pronounced with three identified loss periods.[4] Most of the nitrogen and phosphorus loss occurred when the plants were newly established and correspond to plowing and soil cover treatments evaluated in Section 8.6.

The 24 cleanup treatments are potential treatments for a variety of soils and crops grown in the desert, grassland, or forest. Representative groupings of species for different purposes are shown in Table 8-4 with the environment in which they are being produced. A number of the contaminant removal techniques include soil removal to a specified depth and these depths can be compared to the optimum root zone shown in Table 8-5 that each species will permeate in deep soils.

8.3.2 Soil Compaction

The average density of weathered rock fragments in soil is approximately 2.5 times the density of water. Taking the density of air as close to zero, compared to rock, and a mixture of 50 percent air and 50 percent rock, the average density of the mixture would be expected to be about 1.25 times that of water. For most soils with rock minerals as their principal ingredient, the density is near 1.3. In these soils there is a little more rock than air if the density is judged from this discussion.

Our hypothetical soil with 50 percent air would be a mass of small rock fragments, with holes among the solid particles for the air. The rock fragments would not float because they are about 2.5 times heavier than water. After a rain part of the air space is filled with water; in fact,the escape of air can be seen where water is held on soil as in basin irrigation. In most soils the water wets the weathered rock particles and lubricates them with the result that they slide across one another much easier wet than when dry.

The objective in compacting soils is to squeeze the particles close together so the volume occupied by the soil is smaller, and the density is more like rock than air. When the density is near 1.5 to 1.7 plant roots do not penetrate and plant growth is halted. The water sprayed onto soil during compaction is intended to lubricate the particles so they move across one another under pressure from equipment. A list of equipment and the depths to which it compacts the root zone is given in Table 4-2 of Chapter 4. These are the depths to which the soil must be broken apart for crop production if the soils are intended for agriculture.

Table 8-4. Commercial crop species in managed ecosystems.

Ecosystem	Forage/pasture	Row crops/field crops	Orchards
Desert	alfalfa/ladino clover	sugar beets/dry farmed dry beans/dry farmed vegetables/dry farmed	citrus apricot peach
Grasslands	sweet clover/fescues alfalfa/wheatgrasses home grass	corn /winter wheat soybeans /spring wheat sorghum /barley sugar beets/rye	household plants
Deciduous forests	clovers/lespedosa timothy/bluegrass	corn /spring wheat soybeans /oats tobacco vegetables	apple pear peach

Table 8-5. Rooting depths of agricultural crops in fertile, deep, well drained soils.*

Use/species	Rooting depth observed (meters)	Use/species	Rooting depth observed (meters)
Forage		Field Crops	
alfalfa	3-4	wheat	2-3
sweetclover	3	barley	2-3
clover	1-2	rye	2-3
timothy	1	oats	2
		flax	2
Pasture		Orchards	
ladino clover	0.5	citrus	2-3
fescue	1-2	peach	2
wheat grass	3-4	apricot	5
brome grass	1-2	apple	8-10
lespedosa	1	pear	2
blue grass	0.5		
Row Crops		Row Crops	
cotton	1.5-3	sorghum	2-3
sugar beets	1-2	soybeans	1.5-2
dry beans	1.6-1.8	tobacco	1-1.5
corn	2	vegetables	1-4

*Examples are irrigated desert and tall-grass prairie.

8.3.3 Compaction and Runoff

Any description of hydrologic effects originating from clearing large tracts of cultivated land and then resurfacing with an impervious layer depends on having generic predictors available. The net hydrologic effects from resurfacing do have an area-dependent generic factor. Intuitively, the surface-storage of runoff is related to precipitation intensity and to local topographic features. Resurfacing a flat, downwardly concave area creates runoff storage capacity that may enhance groundwater supplies locally, but resurfacing the rolling topography that formerly supported deciduous forest has variable outcomes that are directly dependent on the area involved.

Flood water runoff on the northeastern belt of the former deciduous forests of Ohio was most highly correlated with watershed area. However, there were two distinctly different area-dependent watershed classes, so different that square kilometers of area drained was used as the criterion for dividing the classes. The zone separating the two flood classes was 50 to 75 km^2. Runoff volume correlated best with drainage area size, rainfall intensity, and soil infiltration rate. These three variables were significantly different from random correlates (probability of random correlation being less than 1 percent for all three variables taken together or individually).

The effects of compacting soil on local runoff from micro-areas are well known. Examples are streets that require storm drains and diversion structures, parking lots, building sites, and construction areas in general. Bar-Kochba and Simon[6] rated infiltration rate into surface soil as the most important non-climatic variable in their eastern Ohio study. Reduction of surface water infiltration rates has the obvious effect of increasing runoff and reducing groundwater recharge rates. This effect is less damaging upon 10-km^2 areas in humid precipitation regions than in semi-arid zones where agriculture depends on pumped water for crop production. Thus, the effect of a compacted area in restricting groundwater recharge increases as the hypothetical compacted area is moved westerly along a decreasing precipitation gradient.

8.3.4 Infiltration and Crops

In an intensively studied area, eastern Ohio, the average water infiltration rate for grassed areas was more than twice the intake rate of adjacent row-cropped fields.[6] A soil-series-dependent influence on intake rate was measurable but the relative infiltration rates were consistent among the several soil series within the approximately 40,000-km^2 study area. The higher infiltration rate suggests why runoff is reduced and groundwater recharge increased by grass cover in deciduous forest agriculture. Grass is the preferred cover for drainage waterways because the stems reduce runoff flow velocity and the abundant fibrous roots keep soil aggregates in place against detachment.

8.4 EFFECTS OF CLEANUP PROCEDURES ON AGRICULTURE

Qualitative descriptions of the effects that each of the different cleanup treatments have on agricultural land are presented in this section. The recovery of longer-lived agricultural crops to their precleanup productivity is briefly described in Section 8.5. Quantitative assessment of the impacts of cleanup treatments on agricultural systems is given in Section 8.6 in terms of the estimated times required for return to commercial productivity.

The cleanup procedures described in this section have essentially three different kinds of functions: (1) treatments temporarily holding the contaminant in place, (2) treatments physically removing contaminants which depend upon stabilization after the cleanup to prevent wind or rainfall erosion until rehabilitation occurs, and (3) restriction of access into the area by humans and animals.

The projections made in this section are predicated on the information which was available at the time the literature survey was completed. Serious revisions of these recommendations or rejections of the projected consequences of the cleanup in agricultural lands as more information is obtained appear unlikely. However, a number of publications will soon be available which are indirectly related to cleanup techniques in agricultural areas. Surface mining in the Western states has resulted in a great many techniques being performed for rehabilitation and reclamation of semi-arid and arid lands. These techniques are experimental at present and are being evaluated for their effectiveness at the different sites involved in surface mining. In a few years these experimental methods will have been published in journals which carry reports of experimental research, and subsequently they will be incorporated into books and reports that will be of use to individuals concerned with agricultural land cleanup after a contaminating event. An example of the kind of material to be anticipated from surface mining rehabilitation is the statement in the recently released operating handbook published by Coal Age. This handbook stated in its Foreword:

> This Coal Age operating handbook of underground mining is the first of a series of books planned to cover key areas of present day coal mining operations. Future books in this series will cover strip mining and reclamation,* coal preparation, management, and maintenance.

As noted in Section 8.1 the agricultural areas described as impacted represent the irrigated southwestern desert, the short grass irrigated and dryland agriculture on the west side of the American prairies and grasslands, and from the midcontinent east to the northeastern middle-west of the United States formerly covered by hardwoods and river bottom deciduous forests. The desert area represents a transect across the American Southwest, extending east from the Imperial Valley of California to those irrigated parts of New Mexico and southwest Texas.

The impact of the cleanup treatments on domestic animals is not covered here. It is presumed that rehabilitation of contaminated areas for production of agricultural crops is a prerequisite to any animal husbandry enterprises. The general crops for which cleanup impacts are described generally fall within three groups of cultivars: (1) dryland and irrigated forage crops, (2) commonly produced row crops and small grains, and (3) tree crops ranging from the citrus orchards of the irrigated desert to the stone fruit and pome orchards in originally deciduous forest areas.

(0-1) Natural Rehabilitation

Unlike natural ecosystems, agricultural ecosystems have no capacity to replace the destroyed commercial crop by the same species after cleanup. Since agricultural crops are grown at an energy cost, when this energy is no longer supplied to the system the crops will no longer grow in commercially productive quantities. Waiting for natural rehabilitation to replace an agricultural crop is an unacceptable procedure. The time course of return from agricultural to natural ecosystems (Old Field Studies) has been defined in Chapters 1, 2, and 3 under the heading Man Made Perturbations. Further details for recovery sequences are in each of those chapters in sections headed Recovery after Cleanup. Those descriptions should be reviewed before forecasting the vegetational changes that will occur on abandoned farmland. Ecologic journals are replete with flora succession studies conducted on Old Field farmlands; they do not return to cultivars.

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*Emphasis added.

(1-1) Chemical Stabilization

Containing the contaminant to diminish its redistribution has an immediate and obvious benefit in both hazard reduction and in minimizing the size of the area of ecological impact by later cleanup methods. The function of chemical stabilization in an agricultural system is to prevent redistribution of the deposited contaminant. More than seventy stabilizers are reviewed in Appendix A; those suitable for use in agricultural fields have been designated in Table A-1. With the exception of water-soluble emulsions, application of a preferred chemical stabilizer requires a number of preparatory steps before the field can be treated. The area to be treated must be cleared of vegetation or clearcut, stumped, and grubbed for tree crops, the slash and vegetative refuse removed, and the fields smoothed and either graded or shallow plowed. Most of the "preferred" stabilizers require direct mixing with friable soils before they become effective in preventing resuspension of soil and contaminant particles. Because of this requirement for similar pretreatment, the after effects from most of the chemical stabilizers will be very similar on the farmlands treated.

Chemical stabilizers which deflocculate soil particles, such as sodium chloride, sodium hydroxide, sodium carbonate, and Calgon, are unsuitable for use in western agricultural fields. Although this class of alkaline and high-sodium dispersants would stabilize surface soil, they can only be used in areas which have high levels of precipitation or access to free water in basin irrigation. The requirement for large amounts of water is to assist plants in withstanding the effects of the saline soil that would be produced by these stabilizers. Leaching of the soil for a long period of time before green manure crops would compound the damage these stabilizers produce by removing free salts, resulting in the deflocculated surface soil becoming impervious to water infiltration. Sodium adsorbed on clay disperses mineral particles and prevents water infiltration. Lack of soil moisture prevents subsequent plant growth. Growth of plants prior to extensive water leaching has been found the simplest way to remove the effects of sodium deflocculants and reconstruct soil tilth. Surface incorporation of high quantities of organic matter into the soil is mandatory at the time recovery is instituted. Crop residues from plants produced for organic matter (green manure), or addition of mulch which is worked into the surface soil are standard procedures.

Thirty-six "preferred" stabilizers for agricultural use are listed in Appendix A; 29 of these require reseeding or replanting of the crops to which they are applied. The remaining seven would not destroy the crop to which the stabilizer was applied. Appendix A has an additional list of 22 "acceptable" stabilizers that are acceptable as alternates for use when the preferred stabilizer cannot be used.

Only 9 of the 58 stabilizers can be applied directly on growing crops without totally endangering their commercial value. Two of the nine plant-safe stabilizers require special handling for cropland application; three of the nine that are safe for plants are water emulsions of asphalt or resin, and four are colloidal suspensions of protein.

(1-2) Clearcutting Vegetation

Clearcutting orchards has the same effect as clearing coniferous and deciduous forests insofar as crop production is concerned. It is very improbable that the operators of commercial orchards would depend on stump sprouting, for those species in which it occurs, as a method of creating a replacement orchard. It is more likely that the trees would be removed in toto (treatment 1-3). Clearcutting of irrigated and nonirrigated forage is the normal harvesting procedures and would have no significant impact in cleanup considerations.

Row crops would be eliminated by clearcutting if undertaken before the normal harvest time. Clearcutting is the method of harvest for a number of row crops. Examples are machine-harvested tomatoes, combine harvesting of all the small grains, the harvesting of the various species of maize and sorghums, and the mechanical picking of cotton crops.

The physical structure of agricultural soils would be unaffected by this treatment. Organic matter content would be undisturbed and the fertility levels unchanged. There would be no change in the suitability of seed beds for subsequent crop production.

(1-3) Stumping and Grubbing

With the exception of orchards, this treatment is inappropriate for agricultural crops. The effects of stump chippers and root rakes on eastern orchards would be similar to the effects described for deciduous forests (Section 3.4). This technique would, of course, eliminate any productive capacity of an orchard by eliminating the producing plants.

The physical effects on the soils in the eastern United States would be due primarily to mixing the fertile surface layers with the relatively infertile subsoil layers which the new tree roots would normally penetrate. For desert orchard soils, there would be a small increase in fertility of the lower segments of the profile and little decrease in fertility of the upper parts of the profile. Irrigated desert citrus would be eliminated as a crop, but the effects upon the soil structure would be relatively mild for most undeveloped irrigated desert soils. The principal post-cleanup effects would be the reduction in the fertility of the profile utilized in the new mixed soil surface. This would need correction before reestablishing orchards in the eastern United States. A secondary impact on eastern orchards would be displacement of wildlife from hedgerows and fencelines surrounding the orchards. The measure of any economic impact would be the potential for a reduction in production of those crops dependent upon displaced animals for pollination.

(1-4) Scraping and Grading

The consequences of surface scraping and grading upon any agricultural crop is seasonally dependent. Performing this operation when fields have been harvested and are normally clear of crops would result in removal of substantial portions of the limited organic matter in the desert. It would have essentially no effect in the grassland areas but clearcutting would make it be an extreme perturbation in eastern orchard areas and on any of the growing eastern row crops. Surface soil would be laid bare to wind and water erosion. If the soil were moist at the time of scraping and grading (presumably by heavy equipment such as road graders, land scrapers, and bulldozers), significant compaction would be likely to result (the effects of soil compaction are described in cleanup treatments 2-3, 2-4, and 2-5).

The physical-chemical properties of most agricultural soils would not be greatly changed by scraping and grading (excluding compaction effects). The principal effects would be increased susceptibility to wind or water erosion at the loosened surface. However, there would be little opportunity for excess sedimentation since the basic runoff water diversion structures would be unchanged.

(1-5) Shallow Plowing

Shallow plowing would eliminate an unharvested cultivated crop and, if the crop were near maturity, would create a trashy surface. In the noncropping season its impact would be minimal or insignificant since plowing is a normal operation of agriculture. Plowing with disc equipment would have little impact on standing orchards in either irrigated or rainfed agriculture. The most likely effect would be soil compaction in the wheel tracks, and furrow bottoms resulting from the use of plowshare equipment, if the soil were significantly moist at the time operations were carried out.

The effects overturning the plow layer has on the seed sources, vegetation, and soil erosion processes of semi-arid rangeland sods are overcome in one or two seasons of regrowth. Shallow plowing of less than 10 cm has little impact on survival of grasses but afterward the roughened surface is unsuitable for stabilizing by mechanical compaction because the surface is trashy. Clays and deflocculants would fall among the sod chunks and be lost to subsequent stabilization techniques.

Runoff is reduced by the increase of surface storage in the roughened area but groundwater recharge in the western shortgrass prairie would be unchanged because the subsoils are permanently dry. Surface erosion by wind and water would be unchanged as grass cover is the cure recommended for both erosion mechanisms.

Damage to woody plants is of short duration. Seed stocks would remain and stump and root sprouts would soon revegetate the plowed rangeland. Animal grazing on the new growth may be a problem in establishing regrowth.

(1-6) Deep Plowing

Plowing to a depth of 40 cm would entirely disrupt any of the agricultural crops during their growing season. If the land were fallow, it would eradicate standing orchards, pastures, and rangelands. The fallow season impact in areas with row crops and small grains would be relatively small and approximately analogous to the consequences of shallow plowing (treatment 1-5). Its effect in pastures and rangelands would be a reduction in productivity of one or more growing seasons. On shallow profiles in the short grass prairies it is likely to produce a mixing of the A- and B-horizons, reducing plant growth in subsequent seasons unless fertilization, and possibly reseeding in the drier areas (less than 35 cm mean annual precipitation), is carried out.

(1-7) Soil Cover Less than 25 cm

The significance of the impact on agricultural crops is a direct function of the quality of the soil used for the cover. A soil high in clay would significantly impair aeration in orchard crops and production decline would begin in a few months. Attempts to add soil to areas with row crops would be impractical in terms of attempting to save the crop from the equipment. The minimum impact would occur in those areas which are grassed—either rangelands or irrigated grasses. Sweetclover forages would probably survive but the survival of irrigated forages, such as alfalfa and ladino clover, is uncertain. The basic soil fertility in the root zone would be unchanged by this depth of cover. The principal effects on seed bed suitability for cropping would be fertility changes from the soil added. The soil used for covering would probably not be equal in tilth and fertility to the soil it covers up.

(1-8) Soil Cover 25 to 100 cm

It is improbable that commercial agricultural crops would survive the addition of a soil cover of this depth.

(2-1) Remove Plow Layer

This layer is about the minimum depth that can be removed as a controlled cut by ordinary heavy earthmoving equipment. Soil removal would create a radical disturbance in agricultural land, almost regardless of the crops that were involved. It would totally destroy rangeland grasses, forage crops, irrigated forage crops, small grains, and standing tree crops normally found in orchards. It would represent an especially severe disturbance east of the 2-cm runoff isogram (Figure 8-1). In the short grass prairie this treatment accomplishes complete removal of the A- and a substantial part of the B-horizon with the corresponding loss of the normal organic accumulation upon which the fertility of the land is based. Removal of the organically rich A-horizon in this area would leave the soil with a severe nitrogen deficit.

It is unlikely that any of the standing orchard species would survive removal of the surface 6 inches of soil in the long term, outside of irrigated areas. Minimum effect would be anticipated in those deep-lying desert soils that are normally irrigated for crop production. These generally coarse-textured soils allow a more rapid deep penetration of plant nutrients from surface and shallow subsoil applications into the soil profile than occurs with nonirrigated agriculture. However, removal of this layer in irrigated agriculture would destroy row crops produced there.

(2-2) Remove Shallow Root Zone

On the shallower soils, removal of up to 40 cm of soil profile would eliminate the fertilized root zone where the major dry-farmed crops are grown (i.e., the infertile and highly calcareous regions of the short grass prairie and in some of the caliche areas underlying irrigated deserts). The resulting truncated soil profile would more nearly resemble an unpaved roadway after deep cuts to maintain a uniform grade in hilly terrain. Shallow root zone removal in the tall grass prairies would have relatively little effect since the profile would still contain significant depth and amounts of organic matter below the soil cut away. In crop lands formerly occupied by deciduous forests, this treatment would destroy the agricultural potential of many of the farmed areas, eradicating the entire organic matter content of those soil profiles as well as any residual artificial fertility elements applied to promote production of crops. The phosphate-rich plow layer would be removed and the surface remaining would be more suitable for nonagricultural purposes.

Prevention of erosion is the immediate problem in soil management when the root zone has been stripped to a depth of 40 cm. West of the 2-cm runoff isogram surfaces not naturally compacted or cemented are vulnerable to wind erosion. East of the 2-cm isogram, post-cleanup surface erosion by runoff water would be a severe problem throughout the stripped areas. Uniformly removing 40 cm of soil surface would impair runoff diversion structures normally incorporated into farmlands. Removal of the shallow root zone west of the 2-cm runoff isogram would leave a smooth erodible surface in the place of the roughened trashy surface normally utilized to prevent wind erosion; that is, planting ridges, grass waterways, lister ridges, shallow terraces, and the basic contour structures would be removed. The basic contour structure could be maintained if care were taken during the soil stripping to take the soil along field contours previously constructed for dry farming and irrigation.

The most severe impact in the excavated agricultural areas would be soil erosion. Other serious impacts relate to crop production, i.e., loss of the soil organic matter, and hence loss of soil fertility.

(2-3) Remove Scraping and Grading, Mechanically Stabilize

This treatment would have little impact on the internal structures normal to control of overland water flow in agriculture. The dikes, berms, drainage ditches, grassed waterways, and overfall structures normally present would be devegetated but not basically eradicated. Scraping and grading on grasslands in pasture- and rangelands would remove the surface organic matter layer, subsequently reducing nitrogen availability in the grasslands. The principal consequence would be reduction of sedimentation onto lands adjoining the cleaned up area. Scraping and grading, removing the loosened material, and stabilizing the surface in areas as large as 10 km^2 would significantly reduce sediment loss that would otherwise occur from scraping and grading large areas.

The effects of this treatment and removal of deeper layers of soil to 40 cm were previously described in cleanup treatments 2-1 and 2-2.

The basic physical effects of this cleanup treatment on desert, grassland, and crops grown on the formerly deciduous forest lands have been described in Chapters 1.4, 2.4, and 3.4 (under cleanup treatment 2-3) to which the reader is referred for added detail. The effects and probabilities of wind erosion and runoff erosion by surface flow are discussed there and are not repeated here. The descriptions in Chapter 2 (Prairies) are especially pertinent to cleanup in areas producing grasses under dryland conditions and for both native and reseeded vegetation on rangelands.

The number of mechanical stabilization procedures that can be used in agricultural areas to be returned to croplands is limited. The slopes in cropped areas are not usually steep enough to require that meshes, nettings, or plastic films be laid in the areas involved. Furthermore, the areas to be protected in farmed fields may be so large that substantial problems would arise from attempts to use plastic films as covers. In a relatively short time the plastic would rip and tear and lose its effectiveness in containing contamination. The otherwise usable mechanical stabilizations would subsequently require removal of an additional layer of soil because they are variations of the compaction process.

The success of compaction methodology is directly dependent on the amount of clay in the soil which is compacted. It is unsuccessful in the coarse-textured, sandy soils frequently found in the irrigated desert where reduction of pore space will be sufficient to destroy agricultural crops. Removal of shallow soil and mechanical stabilization by compaction in an orchard would kill the trees in a short time due to the combined effects of poor aeration and severe moisture deficits brought about by preventing precipitation infiltrating into the soil profile of the orchard. If there is enough clay in the surface soil for compaction to be effective, compaction would be relatively permanent in agricultural terms. Return of the area to agricultural productivity would require rippers, subsoil chisels, repeated plowing, and other action to break apart the compacted layer and free the soil aggregates from the effects of prior compression. The offsite surface flow of runoff would have a major impact on adjacent areas. For areas as large as 10 km^2, uncontrolled runoff could be a significant factor downstream. It is also probable that there would be a drastic reduction of the groundwater in an area where 10 km^2 was mechanically compacted for stabilization purposes. It is unlikely that deflocculants such as sodium chloride would be tolerated for lands that were to be returned to agricultural production, so mechanical stabilization or short-term chemicals are needed.

(2-4) Remove Plow Layer, Mechanically Stabilize

The physical effects on the suitability of the cleaned-up area for agricultural crops under this cleanup treatment are essentially the same as those described under cleanup treatment 2-1. The effects of mechanical stabilization would be very similar to those described in treatment 2-3. The principal differences relate to changes in organic matter and soil fertility induced by compaction. Where there is a relatively high water table and a high organic matter content below the compacted area (e.g., from a large root mass), the fields would be subject to anaerobic decomposition of the organic matter and the nitrogen would be reduced to ammonia forms with the potential for its slow volatilization out of the soil profile. Effectively, the nitrogen content of the cropland would be reduced compared to that which existed prior to the cleanup, as in treatment 2-3. Crop production could not be resumed until the compacted area had been broken apart by mechanical means.

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

The effects of this treatment, insofar as agricultural use of the land is concerned, are very similar to those for plow layer and shallow root zone removal. Soil fertility would be reduced more than with removal of the plow layer. The deeper truncation of the soil profile would render revegetation of the rangeland or native pastures unlikely without renovation in the semiarid short grass prairie region. The desert soils on alluvial fans and deeper profiles would be least affected by this treatment. The deeper cutting is likely to have significant effects on surface runoff control structures in the sub-humid and humid agricultural regions. These control and diversion structures would have to be reinstituted before surface stabilization was undertaken if severe erosion effects are to be avoided. The same soil preparation methodology as described for treatments 2-3 and 2-4 would have to be undertaken to neutralize soil compaction disadvantages prior to reestablishing agricultural production.

(2-6) Remove Scraping and Grading, Chemically Stabilize

The physical effects upon agricultural production from this treatment are about the same as the combined effects of cleanup treatments 1-4 and 2-3. The effects of chemical stabilization would not be as long-lasting as the mechanical stabilizing treatments, and in a number of cases immediate revegetation with some variety of the grasses is required where runoff may cause surface erosion. Infiltration into the soil profile is controlled by the soil profile physical and chemical characteristics rather than by the chemical stabilizer applied; hence, it is unaffected by this treatment.

The most suitable chemical stabilizers to use in an agricultural area are those which break down without leaving toxic residues that would impair food values or plant growth at a later time. Some of the chemical stabilizers described in treatment 1-1 would be the stabilizers of choice in this treatment also.

(2-7) Remove Plow Layer, Chemically Stabilize

This is a composite technique described separately under treatments 1-4 and 2-6. The overall consequence is one of reduced soil fertility with seed bed conditions less suitable for reintroduction of agricultural crops than those conditions resulting from treatment 2-6.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

Slicing away the surface profile to a depth of approximately 40 cm would require the greatest application of chemical stabilizers. Loss of the organic debris leaves the grassland soils susceptible to wind erosion, and requires immediate reseeding with grasses to stabilize the soil against runoff in sub-humid to humid regions. Removal of the loosened soil minimizes sedimentation problems downstream in the runoff area but increases flooding potential from runoff out of areas as large as 1 to 10 km^2.

(3-1) Barriers to Exclude People

The most effective fencing for the exclusion of people would be a chain link fence 6 to 10 feet high posing a physical restraint to trespassers.

(3-2) Barriers to Exclude Large Animals

Design of fences to restrain cattle is a well developed technology. Restraining of large game animals, such as elk and moose, is not likely to be a problem in most agriculturally developed areas. Preservation of mechanically and chemically stabilized surfaces would require that large animal traffic be restricted. The hooves of domestic cattle and sheep would rapidly break down either of the stabilized surfaces, especially since the animals are prone to travel single file which concentrates the cutting action of the hooves in a small path.

(3-3) Barriers to Exclude Large and Small Animals

Attempts to eliminate small burrowing animals, such as ground squirrels and gophers, would probably not be successful in large areas. Containment of these animals within the area would be more successful than elimination. Consequently, fencing should be directed towards retention of animals presumed to have become contaminated in the area rather than to keep small mammals out of the area. Horizontally oriented small-mesh fencing in ditches around the cleaned-up area and backfilling to provide a mesh ledge will prevent the escape of both large and small burrowing animals. Because these animals have a relatively limited home range there is not much danger of them transporting large quantities of contaminants significant distances. Fencing of successive containment areas may be the most practical method to deal with burrowing animals. It is assumed that larger animals can be successfully excluded from contaminated areas until the appropriate cleanup treatment has been selected for the area.

(4-1) Asphalt Hard-Surface Stabilization

Consideration of the use of this treatment in an agricultural area should be based on the understanding that it will be a very temporary cover. Since the surface in most agricultural areas will inevitably be disrupted by stray cattle at some time soon after the material is laid down, it cannot be considered to be a permanent way of securing a contaminant. In areas where surface soil experiences freezing and thawing, such as the grassland and deciduous forest areas, frost heaving is likely to be highly destructive to an asphalted or road-oil treated area in a relatively few seasons.

Application of hot road oil or asphalt to an existing crop in agricultural production would be disastrous. In most circumstances the standing agricultural crop would be removed, with the possible exception of tree crops. An agricultural crop must be considered a total loss if the application of asphalt or hot road oil is necessary to hold the contaminant in place until subsequent cleanup treatments are undertaken. Few agricultural crops can resprout and puncture heavy asphalt surfacing. The more damaging effects would include compression tracks introduced by the heavy equipment needed for transporting asphalt or hot road oil across the areas to be treated. Reclamation of the sites will be an extremely expensive process since the oil-soaked or asphalt layers must be removed before agricultural production can be resumed.

(4-2) Concrete Hard-Surface Stabilization

This is the most severe cleanup treatment proposed for use in agricultural areas. The expense of removing the concrete at a later date almost entirely eliminates use of this cover from consideration. It is inappropriate for use in areas as large as 1 to 10 km^2. The transportation costs of recovering and disposing of the large amount of concrete that would be required for even 0.01 km^2 is almost certain to eliminate it from serious consideration in areas where agriculture is to be resumed.

(5-0) Application of Sewage Sludge

The properties of urban sludge are significantly different from farm manures and crop residues. The use of sludge requires highly specialized information in agricultural management practices. Outright recommendations for the application of sludge are unsafe. Urban sludge is still suspected of containing viable viruses and must not be allowed to come into direct contact with the edible portions of plants.

Sludge contains high quantities of industrial wastes at times. Such wastes contain heavy metals which are poisonous to man: lead, cadmium, chromium, copper, and nickel. Other elements hazardous to man (unless proper soil management practices are used) are aluminum in various compounds, arsenic, selenium, antimony, and mercury. Wastes from industrial electroplating processes are extremely high in these particular metals.

Sludge supplies moderate amounts of nitrogen to cropland and increases the organic matter content of soils. Sludge application is not safe for crops grown on acid soils of the former deciduous forest areas for either human consumption or as animal feeds. However, the low solubility of the heavy metal elements in neutral and alkaline soils minimizes these hazards. Sludges contain from 1 to 6 percent nitrogen on a dry-weight basis. Moderate amounts of sludge would supply nitrogen to croplands and significantly increase the organic matter content of the soil. Five to 40 tons of dry matter per hectare will supply nitrogen and organic matter in the alkaline grassland and desert soils. A decay series worked out for breakdown of the organically contained nitrogen indicates that approximately 25 percent of the nitrogen will be available to plants in the first four years the sludge is in the field. Approximately 30 to 60 percent of the nitrogen in the sludge is in an inorganic form and would be readily available to plants in the first year after the sludge application. This soluble nitrogen poses a potential hazard to groundwater supplies. For this reason, large excesses of sludge should not be applied in renewing the organic content of soils following soil removal, scraping and grading of desert soils, or the addition of soil covers at a depth of 25 to 100 cm over croplands.

(6-1) High Pressure Washing (<3 mm)

This cleanup treatment is outside the scope of work for this report.

(6-2) Flooding to 30 cm

One-time flooding for redistribution of the contaminant into the soil profile is outside the scope of work for this report.

(7-0) Soil Amendments Added

Experiments in which a variety of materials have been added to soils for the purpose of preventing plant uptake of hazardous material have been unsuccessful. Contaminants that are adsorbed onto the exchange surfaces of soil minerals become available to plants either by contact exchange between the mineral surface and the root or by normal solution processes. Once a contaminant is no longer retained on the surface soil but has, in fact, penetrated the root zone of agricultural crops, the suggested reclamation procedure is one of management that will produce luxuriant vegetative growth that is discarded. This is accomplished by normal management practice, soil liming where needed in the deciduous area, and large additions of nitrogen, potassium and phosphate to promote luxuriant plant growth where

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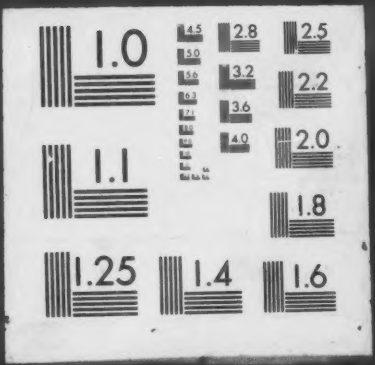
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1.6

water supplies are adequate. In the prairie and desert areas the limiting factor in land reclamation is the water supply. Attempts to immobilize heavy metals to avoid plant uptake in the deciduous area have been unsuccessful. Breakdown of the sludge releases nitrates, sulfates, and other acid forms which will readily consume the added lime and result in highly acid soils from which plants readily extract the injurious metals contained in the sludge.

8.5 RECOVERY FOLLOWING CLEANUP

8.5.1 Irreversible Changes

The complement of cleanup techniques discussed in this report has no irreversible changes. The limits to recovery of croplands are economic; the question is whether to rehabilitate the spill area, soils, and crops. The limits to the use of the most damaging cleanup practices, asphalt (treatment 4-1) and concrete (treatment 4-2), are the cost and effort required to install the asphalt/concrete cover and remove it later. The soils under these two hard surfaces are damaged more by compaction than by seepage of chemicals. Compaction can be rectified mechanically, as highway reconstruction and relocation have shown.

8.5.2 Rates of Recovery

In this chapter all the cropping systems that are discussed have been created by energy input by man. The rates of recovery from cleanup are directly proportional to the energy input expended for rehabilitation in agricultural systems. None of the agricultural systems described will rehabilitate themselves to commercially viable levels once cleanup has been performed. Agricultural systems do not follow the concept of species succession through intermediate stages to climax as described in Appendix B for natural ecosystems. They follow the growth pattern of one individual plant.

Few of the environmental insults that may have extremely large impacts in natural systems would have significant impacts in nonorchard agricultural systems. Agricultural systems normally have structures appropriate for control of erosion by wind or water runoff. The suggested cleanup treatments need not destroy structures.

Rangeland and pasture grasses would need reseeding and modest nitrogen fertilization to recover their productivity. Precipitation controls the rate of recovery to be expected. Unusually intense rainfall would float the seed away and drought would kill the seedlings after germination. In normal weather, productivity on rainfed land is regained in 2 to 3 growing seasons.

Row crops, small grains, and field crops would need the same management they are given each season for normal productivity. The same recovery scheme is appropriate to nontree irrigated crops. Land leveling for irrigation is more severe than any of the recommended cleanup techniques; only mechanical stabilization and asphalt/concrete resurfacing are more disturbing than resloping a field for irrigation.

Orchards would require replanting after any but cleanup treatments 1-1, 5-0, and 7-0. First fruit bearing would begin in 5 to 6 years and full production by 10 to 12 years, including citrus.

The general case for recovery of row crops, small grains, irrigated, and rainfed pastures follows the sequence imposed by natural disasters such as drought, fire, or flooding. Tree orchards likewise have as their recovery model the growth and management steps that would follow renovation of an old, declining orchard.

8.6 QUANTITATIVE ASSESSMENT OF CLEANUP IMPACTS

The impact assessment assumes in cleanup treatments that the contaminant is on the surface soil initially, and that clearcutting is carried out before any of the other temporary containment and removal measures (1-3 through 2-2, 2-3 through 2-8, and 4-1 and 4-2) are performed. Tree crops are assumed to be entirely removed prior to soil manipulation, including root removal (treatment 1-3).

All erosion control devices for runoff are expected to remain functional in the eastern hardwood croplands.

The impacts in this chapter require the intervention of man in almost all cases after a cleanup treatment has been performed. The multitude of corrective actions possible with four kinds of crops (forages and pasture, row crops, small grains, and citrus, stonefruit and pome orchards), 24 cleanup techniques, and three ecosystems (desert, grassland, and deciduous forest) requires that the impact analysis be general and easily reproduced. To that end the impact indexing system is shown here for reference.

Response Required to Resume Production	Index Number*
No measurable impact, no correction needed	0
Loss ends with crop directly exposed to contaminant	1
Restored by normal agricultural practice for that crop	2
One renovating technique required for crop next year**	3
Two renovating techniques required for crop next year**	4
Three or more renovating techniques required for crop next year**	5
Renovation restores crop production in second growing season**	6
Greater than 5 seasons for commercial crop	7
Greater than 10 seasons for commercial crop	8

The soil profile and climatic variables for pasture and grassed range are discussed in Chapter 2.6. Removing 40 cm of soil on the Rocky Mountain side of the shortgrass prairie cuts into the alkaline B-horizons. In that region natural precipitation is too low for maize and orchards. On the Iowa side of the grasslands revegetation will recover almost spontaneously in rainfed pastures.

Cleanup techniques that are similar in impact intensity to normal farming are mowing (1-2) forage and pastures; shallow plowing (1-5) and scraping and grading (1-4, 2-1) are similar to land leveling and are readily erased by the usual seed bed preparation in row crops and small grains. Trees are entirely traumatized by clearcutting (1-2); thus stumping and grubbing and subsequent operations have no additional effect on the tree crop. Trees in orchards in the broad sense are totally destroyed by cleanup. They survive contamination retention processes and soil amendment but not any of the standard decontamination procedures where soil is moved about.

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*All treatments requiring unusual treatments for regaining productivity are equivalent to conditionally retrogressive (Index Number = N+2).

**Renovating techniques are early reseeding, early transplants, annual fertilizer additions, mulching, unusual irrigation, reterracing, recontouring, and other substantial, unusual treatments such as early summer defoliation of orchards.

No significant physical impact on the land occurs when barriers (3-0) are used, but the economic impact caused to the owner by lack of resource availability may be severe. This is true in all the systems reviewed and for normal fertilization (7-0). Recommended chemical stabilizers (1-1) have a similar impact across the species and soils and cause the loss of the standing contaminated crop from the sprays and machinery used in the fields. Clearcutting (1-1) forage and pastures is ordinary mowing and likewise costs one cutting of one crop. On row crops the entire crop seasons' product is lost from clearcutting (1-1) unless it occurs at harvest time. Sludge applications (5-0) are risky and surface applications are limited to fields that grow animal feeds or to citrus orchards if injected into the subsoil.

Rendering the surface impervious to precipitation entry has two effects, deficits in subsurface stored water and downstream channel flooding, whether it is accomplished by soil compaction (treatments 2-3, 2-4, and 2-5) or by paving (treatments 4-1 and 4-2). Groundwater in the treated zone is cut off from local recharge and channel flow becomes proportional to the incidence, intensity, and duration of precipitation once the surface threshold for wetting is reached. Erosion control structures would need to be maintained on all farms to handle the increased runoff from soil stabilizers.

Loosening the surface soil by plowing (1-5, 1-6) and using soil covers (1-7, 1-8) can lead to enormous runoff erosion losses but are otherwise nontraumatic to forage, pastures, and small grains. Land leveling fills is similar to treatment 1-4, and erosion control terracing and contouring fields are analogous to treatment 1-8.

Hardsurfacing treatments (4-1 and 4-2) are likely to be acceptable on a few acres if they are removed later or the land is condemned. The concrete or asphalt residues are not especially harmful to plants where they have been mixed with the soil. Removal of slabs might be expensive but hard surfacing has features of retention that other treatments lack.

No treatments were judged entirely prohibited on a reclamation basis, except some chemical stabilizers.

Successful soil compaction increases runoff from rainfall to high percentages. The proportion may increase to three-quarters of the local precipitation, and downstream flooding is assured in areas as large as 1.0 km^2. The degree of success in compaction sets the magnitude of impact afterward for degrees of hazard. An effective resurfacing depends on low organic matter content in the soil and high clay. These are soil characteristics of the deciduous forest agricultural areas. Cleanup treatments 2-3, 2-4, and 2-5 have been given consistently high recovery time indices in all nontree crops in deciduous areas, and lesser impact recovery time indices in prairie. Mechanical compaction is impaired in prairie fields by the high organic matter residue in the profile, even if 40 cm of topsoil is removed as in treatment 2-5.

Lands in crops will have basic erosion control structures in place before cleanup where wind or water erosion is predictable; however, as the area compacted increases in size, effects on underlying groundwater tables and adjoining water sheds become more severe. Community flood control structures needed for 1.0- and 10-km^2 fields would exist in deciduous agricultural zones.

Desert crop system impact indices are shown in Table 8-6. Removing soil and chemically or mechanically stabilizing the fields has relatively low impact because the coarsely textured soils pack together poorly and plant nutrients are dispersed vertically throughout the profile. Surface soil removal has less impact on fertility than in other land types, and a lower impact recovery time index rating. Soil renovation practices needed for recovery are ordinary irrigation management practices in irrigated agriculture. Soil chisels and heavy fertilization are common.

Grasslands in small grains and irrigated row crops have deep lying nitrogen reserves in the soil profile and are less impacted than the shallower profile on the forested land types. The relative impact index for grasslands under cleanup is given in Table 8-7. Soil cover in grasslands may add weed seeds and be infertile, which has more impact than in forested lands which are of lower fertility initially.

Removing the upper profile has severe impact on later crops in the deciduous forest land type by removing fertility in organic matter and nutrients. The deeper cuts have greater impact as shown in Table 8-8. Runoff

Table 8-6. Predicted recovery index of irrigated desert agriculture for cleanup treatments (see Appendix B).

Treatment	Forage/Pastures Area Disturbed (km^2)				Row Crops Area Disturbed (km^2)				Citrus Orchards Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	0.01	0.1	1.0	10.0	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not appropriate for agriculture
1-1 Chemical Stabilization	1	1	1	1	1	1	1	1	1	1	1	1	Ranked for proteins and emulsions only
1-2 Remove Vegetation by Clear Cutting	1	1	1	1	1	1	1	1	8	8	8	8	Midsummer clearcut assumed
1-3 Remove Stumps and Grub Roots	NA	NA	NA	NA	NA	NA	NA	NA	8	8	8	8	
1-4 Surface Scraping and Grading (<5 cm)	4	4	4	5	4	4	4	5	8	8	8	8	
1-5 Shallow Plowing (<10 cm)	3	3	3	3	3	3	3	3	8	8	8	8	
1-6 Deep Plowing (10 to 40 cm)	3	3	3	3	3	3	3	3	8	8	8	8	
1-7 Soil Cover (<25 cm)	2	2	2	2	2	2	2	2	8	8	8	8	
1-8 Soil Burial (25 to 100 cm)	3	3	3	3	3	3	3	3	8	8	8	8	
2-1 Remove Plow Layer Soil (10 cm)	2	2	2	3	2	2	2	3	8	8	8	8	
2-2 Remove Shallow Root Zone Soil (<40 cm)	3	3	3	3	3	3	3	3	8	8	8	8	
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	3	3	3	4	3	3	3	4	8	8	8	8	Sandy soils stabilize poorly, less impact
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	3	3	3	4	3	3	3	4	8	8	8	8	Sandy soils stabilize poorly, less impact
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	3	3	3	4	3	3	3	4	8	8	8	8	Sandy soils stabilize poorly, less impact
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	3	3	3	4	3	3	3	4	8	8	8	8	
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	3	3	3	4	3	3	3	4	8	8	8	8	
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	3	3	3	4	3	3	3	4	8	8	8	8	
3-1 Barriers to Exclude People	0	0	0	0	0	0	0	0	0	0	0	0	
3-2 Barriers to Exclude Large Animals	0	0	0	0	0	0	0	0	0	0	0	0	
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	0	0	0	0	0	0	0	0	
4-1 Asphalt Hard-Surface Stabilization	5	NA	*	*	5	NA	*	*	NA	NA	*	*	Assumes retrieval feasible before crops needed
4-2 Concrete Hard-Surface Stabilization	5	NA	*	*	5	NA	*	*	NA	NA	*	*	Assumes retrieval feasible before crops needed
5-0 Sewage Sludge Application	2	2	2	2	NA	NA	NA	NA	2	2	2	2	Inappropriate for unrefined human foods
6-1 Washing (<3 mm)	*	*	*	*	*	*	*	*	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	*	*	*	*	*	*	*	*	
7-0 Soil Amendments Added	0	0	0	0	0	0	0	0	0	0	0	0	

*Outside scope of work.
NA - Not Appropriate

Table 8-7. Predicted recovery index of agricultural lands in grasslands for cleanup treatments (see Appendix B).

Treatment	Forage/Pastures Area Disturbed (km^2)				Irrigated Row Crops Area Disturbed (km^2)				Dry Farmed Small Grains Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	0.01	0.1	1.0	10.0	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not appropriate to agriculture
1-1 Chemical Stabilization	1	1	1	1	1	1	1	1	1	1	1	1	Ranked for proteins and emulsions only
1-2 Remove Vegetation by Clear Cutting	1	1	1	1	1	1	1	1	1	1	1	1	Midsummer clearcut assumed
1-3 Remove Stumps and Grub Roots	NA	NA	NA	NA	2	2	2	2	NA	NA	NA	NA	
1-4 Surface Scraping and Grading (<5 cm)	3	3	3	3	3	3	3	3	3	3	3	3	
1-5 Shallow Plowing (<10 cm)	2	2	2	2	2	2	2	2	2	2	2	2	Grass resprouts pptn dependent
1-6 Deep Plowing (10 to 40 cm)	4	3	3	3	3	3	3	3	3	3	3	3	Needs organic matter added
1-7 Soil Cover (<25 cm)	4	4	4	4	4	4	4	4	4	4	4	4	Needs stabilizing and reseeding
1-8 Soil Burial (25 to 100 cm)	4	4	4	4	4	4	4	4	4	4	4	4	Stabilize, fertilize, and reseed
2-1 Remove Plow Layer Soil (10 cm)	3	3	3	3	3	3	3	3	3	3	3	3	Needs early grass reseeding
2-2 Remove Shallow Root Zone Soil (<40 cm)	4	4	4	4	4	4	4	4	4	4	4	4	Needs fertilizer and early grass reseeding
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	2	2	2	2	2	2	2	2	2	2	2	2	Not effective on trashy surface
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	3	3	3	3	3	3	3	3	3	3	3	3	Not effective on trashy surface
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	4	4	4	4	4	4	4	4	4	4	4	4	Needs fertilizer and plowing and grass
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	2	2	2	2	2	2	2	2	2	2	2	2	Needs early reseeding with grass or grain
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	3	3	3	3	3	3	3	3	3	3	3	3	Needs early reseeding with grass or grain
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	4	4	4	4	4	4	4	4	4	4	4	4	Needs early reseeding with grass or grain
3-1 Barriers to Exclude People	0	0	0	0	0	0	0	0	0	0	0	0	Requires structural erosion prevention
3-2 Barriers to Exclude Large Animals	0	0	0	0	0	0	0	0	0	0	0	0	(after crop dies)
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	0	0	0	0	0	0	0	0	
4-1 Asphalt Hard-Surface Stabilization	5	NA	*	*	5	NA	*	*	5	NA	*	*	Assumes retrieval before crops again
4-2 Concrete Hard-Surface Stabilization	5	NA	*	*	5	NA	*	*	5	NA	*	*	Assumes retrieval before crops again
5-0 Sewage Sludge Application	2	2	2	2	NA	NA	NA	NA	NA	NA	NA	NA	Inappropriate for unrefined human foods
6-1 Washing (<3 mm)	*	*	*	*	*	*	*	*	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	*	*	*	*	*	*	*	*	
7-0 Soil Amendments Added	0	0	0	0	0	0	0	0	0	0	0	0	

*Outside scope of work.
NA - Not Appropriate

Table 8-8. Predicted recovery index of agricultural lands in forests for cleanup treatments (see Appendix B).

Treatment	Forage/Pasture Area Disturbed (km^2)				Row/Field Crops Area Disturbed (km^2)				Area Disturbed (km^2)				Assumptions
	0.01	0.1	1.0	10.0	0.01	0.1	1.0	10.0	0.01	0.1	1.0	10.0	
0-1 Natural Rehabilitation	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	Not appropriate for agriculture
1-1 Chemical Stabilization	1	1	1	1	1	1	1	1	1	1	1	1	Ranked for protein or emulsions only
1-2 Remove Vegetation by Clear Cutting	1	1	1	1	1	1	1	1	8	8	8	8	Midsummer clearcut assumed
1-3 Remove Stumps and Grub Roots	NA	NA	NA	NA	NA	NA	NA	NA	8	8	8	8	
1-4 Surface Scraping and Grading (<5 cm)	4	4	4	5	4	4	4	5	8	8	8	8	
1-5 Shallow Plowing (<10 cm)	3	3	3	3	3	3	3	3	8	8	8	8	
1-6 Deep Plowing (10 to 40 cm)	3	3	3	4	3	3	3	4	8	8	8	8	Needs organic matter
1-7 Soil Cover (<25 cm)	2	2	2	2	2	2	2	2	8	8	8	8	Needs mulch
1-8 Soil Burial (25 to 100 cm)	3	3	3	3	3	3	3	3	8	8	8	8	Needs fertilizer and mulch cover
2-1 Remove Plow Layer Soil (10 cm)	3	3	3	3	3	3	3	3	8	8	8	8	Needs fertilizer and organic matter
2-2 Remove Shallow Root Zone Soil (<40 cm)	4	4	4	5	4	4	4	5	8	8	8	8	Needs fertilizer, organic matter, and mulch
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	4	4	4	4	4	4	4	4	8	8	8	8	Requires erosion control maintenance
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	4	4	4	4	4	4	4	4	8	8	8	8	Requires erosion control maintenance
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	6	6	6	6	6	6	6	6	8	8	8	8	Requires erosion control maintenance
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	4	4	4	4	3	3	3	3	8	8	8	8	
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	4	4	4	4	3	3	3	3	8	8	8	8	Needs fertilizer
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	4	4	4	4	3	3	3	3	8	8	8	8	Needs fertilizer and organic matter
3-1 Barriers to Exclude People	0	0	0	0	0	0	0	0	0	0	0	0	Old field retrogression after one year
3-2 Barriers to Exclude Large Animals	0	0	0	0	0	0	0	0	0	0	0	0	Old field retrogression after one year
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	0	0	0	0	0	0	0	0	Old field retrogression after one year
4-1 Asphalt Hard-Surface Stabilization	5	NA	*	*	5	NA	*	*	8	8	*	*	Assumes retrieval before needed
4-2 Concrete Hard-Surface Stabilization	5	NA	*	*	5	NA	*	*	8	8	*	*	Assumes retrieval before needed
5-0 Sewage Sludge Applica*'on	2	2	2	2	NA	NA	NA	NA	4	4	4	4	Not for unrefined food crops; for cotton and trees
6-1 Washing (<3 mm)	*	*	*	*	*	*	*	*	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	*	*	*	*	*	*	*	*	
7-0 Soil Amendments Added	0	0	0	0	0	0	0	0	0	0	0	0	

*Outside scope of work.

NA - Not Appropriate

erosion is more of a problem because the deep cuts on pastures remove progressively more grass roots that have bound soil together. Row crops generally are on flatter slopes in well managed farms where erosion is less severe than on scalped pastures.

8.7 CONCLUSIONS

The preferred cleanup treatments are those which isolate the food chain from man. For small areas this may include fencing (treatment 3-1) or applying hard surfaces (treatments 4-1 and 4-2) to a small area with the expectation that they will be retrieved at a later date. Shallow or deep plowing to 40 cm is acceptable with the exception of eastern orchards which might suffer moderate root pruning from deep plowing. Seven of the chemical stabilizers recommended for agricultural use would be appropriate in short-term response to a contaminating event.

Cleanup techniques which are inappropriate in an agricultural area expected to be returned to crop production are those which involve dispersing soil by the addition of sodium compounds in large quantities, particularly in either desert or semi-arid grassland areas. Removal of the shallow root zone soil to 40 cm depth should not be considered for areas larger than 1 or 2 hectares because the problem of disposing of the contaminated soil is a greater problem than other ways of decontaminating. Although fenced areas to exclude cattle have been recommended in the natural ecosystems as a preferred treatment, they are not recommended here because of their position near the top of the food chain leading to man. It is almost inevitable that domestic cattle would breach fencing in grassland or deciduous forest areas if the land is left fenced for more than a few months.

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CHAPTER 9

URBAN/SUBURBAN AREAS

9.1 OVERVIEW

Urban/suburban areas differ from the agricultural and undeveloped areas addressed in other chapters of this report in a number of ways that affect the reclamation decisions and their impacts.

The characteristics of urban/suburban areas that may influence the cleanup strategies and procedures are diverse. At one extreme, urban/suburban areas include downtown areas of major cities which are completely covered by buildings and pavements, with residential and transient populations numbering hundreds of thousands of people per square mile at any one time. In contrast, urban/suburban areas also include single-family homes on spacious lots with only a small fraction of the land area covered by buildings and paved walkways and roadways, and with populations of, at most, a few thousand persons per square mile. Between these extremes are various other types of land use classes, such as commercial and industrial sections. In addition, within an area of certain overall characteristics, such as a residential area of single-family homes, great diversity can exist. Such places can have significant park and recreational areas, scattered shopping centers and other commercial areas, and undeveloped areas.*

In addition to the diversity of population density and land use and the degree of structural buildup, a particular area will have other characteristics that influence the cleanup options. Some of these factors are: the surface and subsurface hydrology of the area, the existing sewer and storm-drain system, availability of equipment and manpower, the source of water supply (including areas outside the affected area whose water supply might become contaminated unless care is taken), season of the year (e.g., whether the ground is frozen or covered with snow), and short-term meteorology (e.g., humidity, winds, likelihood of rain).

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*Undeveloped areas within urban/suburban areas are not addressed in this chapter. For these areas, the land type which best describes the undeveloped area should be determined and the appropriate chapter in this report referred to while recognizing that the greater likelihood of human exposure in the vicinity of urban/suburban areas may require special considerations as to the cleanup techniques.

From this discussion it must be recognized that for any particular incident that releases contaminating materials in an urban/suburban area, the courses of action and the effectiveness and consequences of such actions are highly dependent on the specific situation. However, it is useful to attempt to describe a "typical" urban/suburban area. One important characteristic is the fraction of land area that is covered by (1) impervious surfaces such as roofs, paved walkways and road areas, and (2) permeable surfaces consisting of lawns, plants and trees, and bare earth. Each of these types of areas requires different cleanup techniques having different environmental impacts.

The Census Bureau defines an "urbanized area" as a central city (or contiguous cities) with a total population in excess of 50,000 plus the surrounding "closely held" populated areas, i.e., what is generally thought of as an urban area and its suburbs (exclusive of large parks, golf courses, cemeteries, etc.). Based on 1970 Census data, there were 248 such urbanized areas in the United States with a total land area of 35,081 square miles and a total population of 118,446,566 people, or 58 percent of the total U.S. population. Thus, according to the U.S. Bureau of the Census[6], the average population density in urbanized areas is 3,376 people per square mile.

National statistics regarding the fraction of ground surface covered by streets, buildings and permeable surfaces in urban/suburban areas could not be found, so residential areas in Santa Barbara, California, were randomly selected and surveyed to develop these statistics. The population density of the "place" of Santa Barbara is 3,333 people per square mile[6], which is in excellent agreement with the average population density of urbanized areas, so it is assumed that statistics for Santa Barbara are reasonably representative of typical urban/suburban areas of the Nation.

Within single-family housing tracts of Santa Barbara, the approximate coverage of the ground surface area is 20 percent by buildings; 15 percent by streets; 8 percent by driveways, sidewalks, walkways, patios, etc.; and the remaining 57 percent by lawn and soil areas. Thus within housing tracts, the impervious surfaces comprise approximately 43 percent of the surface area. Such single-family housing tracts that are fully developed have population densities of approximately 10,000 persons per square mile.

The above statistics are applicable for small areas within fully developed single-family housing tracts. Within a larger area, the permanent population density is less because of commercial areas, open spaces, etc., and therefore the proportion of the area which is covered by impervious surfaces may differ. A recent study was concerned with the recharge of groundwaters in suburban areas of Santa Barbara.[4] Within the area of interest of that study, which can be described as primarily residential single-family suburban housing tract areas (upper-middle to middle income housing), the population density is approximately 3,500 to 4,500 persons per square mile (i.e., roughly in agreement with the typical population density of an urbanized area). The ground surface consists of approximately 37 percent impervious surfaces (buildings, streets, etc.), 24 percent lawn and yard areas, 9 percent agricultural areas, and 30 percent open space and native vegetation areas. Thus it can be seen that a surprisingly large percentage of a suburban area (39 percent for the case of Santa Barbara) consists of areas having "rural" or "natural" characteristics. However, the percent of surface which is impervious is not much less than the value of 43 percent within housing tracts.

It is estimated that approximately one-half of the rainfall from small storms in Santa Barbara that falls on impervious surfaces finds its way to storm sewer systems with the remaining one-half soaking into the ground.[4] Therefore, if the cleanup option is to flush the contaminant from building roofs, streets, and walkways with water, approximately one-half of the contaminated water can be expected to soak into the ground unless measures are taken to prevent this occurrence.

Other data for the upper Santa Ana Valley in California indicate that the fraction of land area which is covered by impervious surfaces varies linearly from approximately 20 percent for an area that is 40 percent urban developed to approximately 70 percent for an area that is 100 percent urban developed.[4] For the Santa Barbara area, which is approximately 60 percent urban developed, the ground surface should be approximately 38 percent covered by impervious surfaces. This is in excellent agreement with the actual value of 37 percent.

In summary, the characteristics of small areas of 0.01 km^2 in size within an urbanized area may vary considerably. If one randomly selects a small area within an urbanized areas, the probability is approximately 40 percent that the area will have "rural" or "natural" characteristics rather than urban characteristics. As the area of contamination is increased to the maximum of 10 km^2 used in this study, the characteristics of the area approach the average characteristics of 60 percent urban developed with 37 percent of the land covered by impervious surfaces and a population density of approximately 3,400 people per square mile.

9.2 NATURAL PERTURBATIONS

Natural perturbations that produce some of the environmental effects that could occur from cleanup treatments in urban/suburban areas include most of the natural disasters, i.e., floods, fires, earthquakes, and severe storms. In most cases, these natural perturbations will have significant effects on man-made structures; whereas the reclamation treatments will have little adverse effects. In contrast, some of the reclamation techniques will typically have more adverse effects on the "natural" ecology of urban/suburban areas than do natural disasters. For example, removing 40 cm of soil will destroy essentially all vegetation, whereas no natural disaster is likely to produce this degree of total destruction.

9.3 MAN-MADE PERTURBATIONS

A number of activities of man can cause destruction to the man-made environment and the natural environment of urban/suburban areas. Such activities include war, urban development or redevelopment, and spills of hazardous materials.

The normal construction activities associated with urban development or redevelopment usually employ most of the cleanup techniques that are discussed in Section 9.4. Typically, earthmoving and destruction of vegetation are required to prepare land for development. By design, the land is not allowed to return to its natural condition; instead, lawns are established and desirable trees and smaller plants are planted. Within a few months to a couple of years the desired vegetation, except large trees, is established.

Spills of materials that are hazardous or ecologically damaging require cleanup techniques identical or similar to the treatments for cleanup of radioactive material. Again, in the urban/suburban situation there is usually no significant lasting effect (except for social and economic impacts) because the artificial man-made environment that is disturbed by the treatment can usually be reestablished relatively quickly. An exception to this statement would occur if the contamination could not be cleaned up to the necessary degree, forcing restriction or abandonment of an urban/suburban area or removal of structures. However, even in this case the impact is primarily social and economic, with little additional effect on the natural environment.

9.4 EFFECTS OF CLEANUP PROCEDURES ON URBAN/SUBURBAN AREAS

The urban/suburban environment is largely a man-made environment, in contrast to the natural environments of undeveloped areas. Some cleanup options that might cause significant environmental impact in undeveloped areas (e.g., vegetation clearing, removal of soil layers, and applying soil cover) are common activities in urban/suburban areas.

Because of the greater hazard to humans from contamination of urban/suburban areas, a greater cleanup effort is not only justified but required. To clean up the area to the maximum possible extent, a series of cleanup techniques would probably be used rather than a single technique. The effectiveness of the cleanup is primarily limited only by the monetary cost of carrying out the tasks. For example, contaminated roofs could be stripped of shingles and reshingled if necessary. Contaminated pavements could even be removed. In an urban/suburban area, virtually the entire surface area could be stripped and removed without significant impact on the "natural" ecology—but with a high monetary and social cost.

Treatments that can be used in urban/suburban areas to remove contaminants or to reduce the hazard from such contaminants can be grouped into those that lend themselves to application for lawn, plant, and soil areas in yards and parks (treatments 1-1 through 7-0 in the following list), and those that lend themselves to application for hard, relatively impervious, artificial surfaces, such as building roofs, walkways, and paved areas (treatments 8-1 through 8-7 in the following list).

Treatments for Lawn, Plant and Soil Areas*

0-1 Natural Rehabilitation

1-1 Chemical Stabilization
1-2 Clear Cutting Vegetation
1-3 Stumping and Grubbing
1-4 Scraping and Grading
1-5 Shallow Plowing
1-6 Deep Plowing
1-7 Soil Cover Less than 25 cm
1-8 Soil Cover 25 to 100 cm

2-1 Remove Plow Layer
2-2 Remove Shallow Root Zone
2-3 Remove Scraping and Grading, Mechanically Stabilize
2-4 Remove Plow Layer, Mechanically Stabilize
2-5 Remove Shallow Root Zone, Mechanically Stabilize
2-6 Remove Scraping and Grading, Chemically Stabilize
2-7 Remove Plow Layer, Chemically Stabilize
2-8 Remove Shallow Root Zone, Chemically Stabilize

3-1 Barriers to Exclude People
3-2 Exclude Large Animals
3-3 Exclude Large and Small Animals

4-1 Asphalt Hard Surface Stabilization
4-2 Concrete Hard Surface Stabilization

5-0 Application of Sewage Sludge

6-1 High Pressure Washing (<3 mm)
6-2 Flooding to 30 cm

7-0 Soil Amendments Added

Treatments for Hard, Impervious, Artificial Surfaces

8-1 Washing with High-Pressure Water (Firehosing)
8-2 Vacuuming
8-3 Sweeping
8-4 Mechanized Street Flushing
8-5 Surface Removal Techniques
8-6 Other Removal Methods
8-7 Containment

In general, treatments 1-1 through 1-8 are not treatments for the removal of a contaminant (although 1-2 is a removal treatment if contamination of vegetation is significant). Instead, these treatments are those that might be applied as a temporary measure to hold the contaminant in place to prevent its redistribution. In the case of treatments 1-5 through 1-8, the immediate hazard is reduced because the contaminant is shielded by soil cover.

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*This list of treatments applies to all land types, and is included for a complete discussion. Some of these treatments are not appropriate for urban/suburban areas.

Treatments 1-1 through 7-0 apply to land types in general. Most of these treatments also apply for the lawn, plant, and soil areas (yards) of urban/suburban areas. However, in the urban/suburban situation some of the treatments may be more appropriate than others and the environmental impacts may be significantly different than would be the case for an undeveloped or agricultural area.

Because of the greater potential hazard from a contaminating incident in a populated area, several of the treatments might be used on urban/suburban yards so as to reduce the hazard to the maximum practical extent. For example, a stabilizer might be applied to lawns to hold the contaminant in place while the sod is removed and any residual contamination hazard might be further reduced by turning over the soil before resodding.

Depending on circumstances it may be desirable or it may be undesirable to coat the ground with a sealant, such as liquid asphalt, so that contaminated water from washing of roofs and walkways will run off into the storm drain system rather than soak into the soil.

Flushing with water or blowing with compressed air may remove the contaminant from the foliage of plants if the resuspension in air or the washing into the soil of the contaminant is acceptable. Otherwise, the contaminant can be fixed onto the leaves of the plant by a stabilizer and then the plant can be pruned, defoliated, or removed.

Some of the treatments which are used for cleanup of hard artificial surfaces, such as sweeping and firehosing, can also be used with some limited effectivess on frozen ground.

Each of the potential treatments is discussed below in the order listed. The discussion is based primarily on Owen et al.[5] and to a lesser extent on Bennett and Owen[1] and Cobb and Van Hemert.[2]

9.4.1 Lawn, Plant and Soil Area Treatments

(0-1) Natural Rehabilitation

Because of the proximity of humans, it is assumed that doing nothing to clean up urban/suburban areas is not a viable option; rather, any contamination will have to be reduced to some acceptably low level Therefore, natural restoration does not apply for urban/suburban areas.

(1-1) Chemical Stabilization

The purpose of the chemical stabilizers is to hold the contaminant in place, to prevent redistribution until the contaminant can be removed. The properties of the general classes of chemical stabilizers are given in Appendix A, Soil Stabilizers. Chemical stabilizers vary as to their effectiveness and longevity in holding the contaminant in place and in their effects on vegetation. Some of the stabilizers cannot be used without necessitating subsequent removal of the vegetation.

In lawn areas the sod will undoubtedly be removed and the lawn area reestablished with seed or resodding, in which case the use of chemical stabilizers has no significant adverse environmental effect.

(1-2) Clear Cutting Vegetation

For lawns and ground covers, this treatment consists of mowing or perhaps renovating down to the soil. There is no significant adverse effect from mowing or renovating, since the root zone is not damaged and the grass or ground cover grows back relatively quickly.

In general, clear cutting of bushes and trees is to clear the ground surface for plowing or soil removal. Many bushes, and some trees, will reestablish from the root systems of the clear-cut vegetation, although not as quickly as grass. The time to reestablish varies from a year for small shrubs to many decades for large trees.

(1-3) Stumping and Grubbing

This treatment contributes little additional impact to that which occurs when the trees and bushes are cut down. If trees are cut down, new trees would probably be planted so removal of stumps is desirable. Shrubs would have to be replanted rather than allowed to propagate from existing root systems.

(1-4) Scraping and Grading

The removal of up to 5 cm of soil by scraping and grading is equivalent to removing the sod layer for lawns. Removal of this layer will not have any effect on trees and larger shrubs unless they must be removed to provide room for equipment. Smaller plants may be damaged, but they would likely be removed in any case to ease the task of scraping and grading.

(1-5) Shallow Plowing

The disturbance of the upper 10 cm of soil by shallow plowing will have more significant effects than treatment 1-4. If plowing is done close to small plants they may be killed by root disturbance; but most trees will not be killed or seriously damaged by plowing to this depth.

(1-6) Deep Plowing

Deep plowing (10 to 40 cm) will have more serious effects on trees. Most trees in yards and parks have shallow root systems because of improper watering; plowing to a depth of 40 cm will damage these root systems. However, because of interference by larger roots it may not be possible to plow close to the tree, so many trees that might otherwise be killed by close plowing will survive.

(1-7) Soil Cover less than 25 cm

(1-8) Soil Cover 25 cm to 100 cm

If not only a temporary treatment, and if not removed within a relatively short time period, soil cover in an urban/suburban area will change grade levels and affect water drainage around buildings. As a short-term measure, adding soil cover will not affect trees and larger bushes. Smaller bushes may be covered and killed and lawns will die in a short time period.

Except for palms, trees cannot tolerate the permanent addition of soil unless measures are taken to ensure adequate air circulation about the trunk down to the original grade level. If soil is placed around the trunk, rot will set in and the tree will eventually die. The addition of 25 cm of soil will have no effect on trees if it is kept from the trunk. A 100-cm layer requires a larger space around the trunk to ensure adequate air circulation, and can be expected to affect the root system of the trees by oxygen depletion.

There may be practical limitations on using soil cover. To cover the ground to a depth of 100 cm in one square kilometer of the typical urban area, whose surface is comprised of 63 percent soil and vegetation, requires 824,000 cubic yards (630,000 cubic meters) of fill soil.

Treatments 2-1 through 2-8 are designed to remove a contaminant from yards so that it can be transported to a safe place. These treatments are straightforward—by whatever means are practical, sod and layers of soil are removed until the residual contamination is at an "acceptable" level. In the urban/suburban situation, uncontaminated topsoil will usually have to be brought in as fill to restore yards to the original grade level. Stabilizers might be used to prevent erosion, but stabilization techniques which have adverse effects on the revegetation of the area, such as compacting, would not be required. Stabilization is required only for a relatively short time period while lawns become established.

The depth to which soil can be removed from around a tree without injuring or killing the tree depends on the proximity of the root system to the ground surface. This, in turn, primarily depends on the type of tree, its location, and the watering it has received. Some of the most desirable trees, such as maples and some oaks and conifers, have relatively shallow root systems. Also, because of frequent and shallow watering, trees in yards often develop root systems relatively close to the ground surface; such trees are more susceptible to damage from soil removal than are trees which rely on rainfall.

For lawns, using sod cutters and rolling up the sod for hauling away is effective. Past experiments indicate that this procedure will remove 98 percent to 99 percent of a contaminant. Removing sod by garden tractors or by hand shoveling appears to be less effective in removing contaminant than using a sod cutter, although the data are limited.

Where access is not restricted, larger machinery such as bulldozers, backhoes, road graders, etc., may be used to scrape off the top layers of soil. Typically, for large working areas, removal of 5 to 10 cm of soil will significantly reduce contamination, although results are quite variable. For smaller working areas, such as typical urban/suburban yards, the effectiveness of heavy machinery is limited and it must be supplemented by hand labor.

The magnitude of the disposal problem associated with removing contaminated soil, and the task of hauling in uncontaminated soil for fill, must be appreciated. Removing the plow layer of soil (10 cm) from the "typical" urban/suburban area requires the disposal of 82,400 cubic yards (63,000 cubic meters) of contaminated earth per square kilometer, compacted to the original density. Disturbed earth takes up more volume than undisturbed earth, probably by a factor of 20 to 40 percent, so removing the plow layer of soil from a 10-km^2 typical urban/suburban area requires disposing of approximately one million cubic yards of contaminated earth and hauling in the same volume of uncontaminated earth for fill. Removing soil in the shallow root zone quadruples these requirements.

(2-1) Remove Plow Layer

In the urban/suburban situation there is little impact from removing the top 10 cm of soil from yards. Lawns can be reseeded or resodded, and plants and small bushes can be replaced. Only very shallow-rooted trees will be seriously damaged or killed by the removal of soil to this depth.

(2-2) Remove Shallow Root Zone

Whether or not a tree is killed from removal of 40 cm of soil depends on the particular tree and its situation; however, in general, the removal of this amount of soil will probably kill most trees that do not have significant taproots. The use of heavy equipment will cause more damage than careful use of hand tools.

(2-3) Remove Scraping and Grading, Mechanically Stabilize

Removal of the top 5 cm of soil will have no significant effect on trees and large bushes. This is equivalent to removing the sod layer from lawns. The lawns can be reseeded or resodded, and smaller plants that have been removed can be replaced. Compacting of the soil for erosion control would not be required; other means of stabilization that are practical would have no significant adverse effects.

(2-4) Remove Plow Layer, Mechanically Stabilize

The impact is the same as for treatment 2-1, provided compacting or hard-surface stabilization techniques are not used.

(2-5) Remove Shallow Root Zone, Mechanically Stabilize

The impact is the same as for treatment 2-2, provided compacting or hard-surface stabilization techniques are not used.

(2-6) Remove Scraping and Grading, Chemically Stabilize

The impact is the same as for treatment 2-3.

(2-7) Remove Plow Layer, Chemically Stabilize

The impact is the same as for treatment 2-1.

(2-8) Remove Shallow Root Zone, Chemically Stabilize

The impact is the same as for treatment 2-2.

(3-1) Barriers to Exclude People

This technique is probably practical only as a short-term measure while the contaminant is removed. Barricading people from urban/suburban areas to which they normally have access for longer than a few days or weeks would cause considerable social disruption and adverse economic impact.

(3-2) Exclude Large Animals

Any barrier to exclude large animals would also exclude people, which is unacceptable in an urban/suburban area except for a brief time period. Because of the relative scarcity of large animals in urban/suburban areas, there would be no significant impact on them.

(3-3) Exclude Large and Small Animals

Except for very small areas, exclusion of small animals would be difficult. Household pets would have to be relocated with their owners or impounded. Wild animals, primarily birds and rodents, might multiply. They also might become vectors for spreading a contaminant to other areas.

(4-1) Asphalt Hard-Surface Stabilization

Probably in most cases asphalt hard-surface stabilization would be combined with some degree of plant and soil removal, thus entailing additional logistic and economic problems both for initial treatment and subsequent removal. An asphalt surface would kill any unremoved vegetation. Unremoved trees would die from lack of water and oxygen to the roots.

(4-2) Concrete Hard-Surface Stabilization

The same comments apply as for treatment 4-1, except that concrete would provide a more permanent surface or, if removed, be slightly more difficult to break up and transport.

(5-0) Application of Sewage Sludge

Outside the scope of work.

(6-1) High-Pressure Washing

Outside the scope of work.

(6-2) Flooding to 30 cm

Outside the scope of work.

(7-0) Soil Amendments Added

Outside the scope of work.

9.4.2 Impervious, Artificial Surface Treatments

The treatments that may apply to remove a contaminant from the hard, impervious artificial surfaces that cover much of the urban/suburban land areas are: washing with high-pressure water (treatment 8-1), vacuuming (treatment 8-2), sweeping (treatment 8-3), mechanized street flushing (treatment 8-4), surface removal techniques (treatment 8-5), and other removal techniques (treatment 8-6).

As would be expected, smoother surfaces retain less residual contaminant than rougher surfaces, larger particulates are more effectively removed than smaller particulates, and the fraction of contaminant removed is greater for initially greater loading densities. Data on the effectiveness of the cleanup techniques are primarily based on results of simulations using sand. The particulate sizes were often on the order of 100 microns or more and the surface loading densities on the order of 100 grams/ft^2. For smaller particulates and less dense surface loading, effectiveness should be considerably less.

(8-1) Washing with High-Pressure Water (>3 mm)

Large, impervious areas such as roofs and streets can be cleaned by high-pressure streams of water. The high-pressure water dislodges and dilutes most of the contaminating particles and carries them away in the runoff. In this case, the contaminant is simply being moved to a different location. Detergents, manual or motorized scrubbing, and special hose nozzles may be employed. In general, firehosing has been envisioned as an emergency technique to be used in catastrophic situations to clean up a relatively large populated area where concern with the runoff of contaminated water is secondary to reduction of the immediate hazard.

Examination of results from numerous experiments summarized by Owen et al.[5] indicates that, in general, firehosing will remove 90 percent or more of contaminating particulates from areas paved with asphalt, concrete, and asphaltic concrete. Often less than 1 percent of the residue remained after a single pass. Repeated passes with the water stream removed more contaminant, but with decreasing effectiveness. Contaminants in slurrys appear to be removed as effectively as are particulates. Although roofs are not as effectively firehosed as are street areas, tar-and-gravel and composition shingle roofs can be 90 percent or more decontaminated. Limited data on wood shingles indicate 80 to 90 percent decontamination effectiveness.

Firehosing roofs and paved areas requires 10 to 20 liters of water per square meter of area per pass. To treat a typical suburban area in this manner would require 1 to 2 million gallons (3.7 to 7.4 million liters) of water per square kilometer per pass, exclusive of water needed to wash down vertical surfaces. Even the smallest-sized area of 0.01 km^2 would result in 500 to 1,000 50-gallon drums of wastewater. Thus, except for very small areas, it may not be practical to collect and store contaminated wastewater from cleanup .

Hosing down impermeable surfaces simply moves the bulk of the contaminant to a different location and/or reduces it to more acceptable concentrations. Runoff from structures moves the contaminant to the ground level onto other impermeable surfaces, or onto soil and plants. Flushing walkways and streets moves the contaminant onto soil surfaces or into storm drain systems. If measures are not taken to collect the runoff, shrubs, lawns, and bare earth areas will receive contaminated water as will storm drain discharge points.

Uncontaminated, permeable surfaces can be sealed with substances such as liquid asphalt to prevent contaminated runoff water from soaking into the ground. However, it is unlikely that all splashes can be contained; in fact, it may be desirable in some instances to let contaminated runoff water soak into permeable ground surfaces as a means of contaminant collection. Radioactive contaminants are often quite insoluble and can be effectively filtered by soils, and the portions that are soluble are quickly adsorbed onto surface soil particles. For example, as discussed in *The Behavior of Radioactive Fallout in Soils and Plants,*[3] approximately 99 percent of fallout is insoluble (in distilled water) and a solution of soluble portions poured through the soil in one set of experiments was 80 to 85 percent adsorbed by the first few centimeters of soil. Plutonium, a radionuclide of great concern, is very insoluble in water and might best be trapped by soil filtration and subsequent removal of a layer of soil.

(8-2) Vacuuming

Removal of contaminating particulates from hard surfaces by vacuuming has not been examined in as much detail as other techniques, such as firehosing. The reason for this relative neglect may be because of the slow working rate compared to firehosing. A street can be firehosed at a rate of 300 to 500 square feet per minute compared to a few tens of square feet per minute for vacuuming. Nevertheless, examination of the data from Owen et al.[5] indicates that vacuuming can be effective in removing particulate contamination from hard surfaces. In general, based on a limited number of experiments, vacuuming can remove in excess of 90 percent, and sometimes in excess of 99 percent, of the particulate contamination from composition shingles and concrete with a single "pass." In the single experiment where repeated vacuumings were employed to decontaminate concrete, the second vacuuming removed 90 percent of the residue from the first vacuuming and the third and fourth vacuumings removed about one-half of the remaining residue. Thus, it appears that careful vacuuming can remove in excess of 99 percent of particulate contamination from pavement and roofs. In an experiment for decontaminating frozen bare ground, vacuuming removed about 60 percent of the contaminant after 4 passes (40 percent was removed on the first pass).

Details on the design of the vacuuming experiments are not available, but it is presumed that the particulates were "fresh," i.e., the particulates were not allowed sufficient time to "weather" and become more firmly attached to the contaminated surfaces.

Vacuuming has a significant advantage over firehosing and other types of methods that simply move the contaminant to another location because vacuuming picks up the contaminant and contains it for safe disposal. Care must be taken that absolute filters are used, in addition to the coarse filters in the typical vacuum cleaner, so that very small particulates will be trapped rather than resuspended in the air by the cleaner's exhaust. Otherwise, no adverse environmental effects appear to be associated with vacuuming contaminants from hard surfaces.

(8-3) Sweeping

Mechanized street sweepers can remove significant amounts of contaminants from dry paved surfaces. In experiments few passes of these sweepers typically removed more than 99 percent of the contaminant. Mechanical street sweepers have a realtively high rate of cleaning, e.g., a few thousand square feet per minute per pass. Again, in a large-scale emergency where the primary concern is to reduce the gross hazard as quickly as possible, street sweeping may be a viable technique. However, in cases where it is less critical, street sweepers probably would be a less acceptable alternative due to resuspension of paticulate materials. Dust can be kept down to some extent by sprinkling. In any event, mechanized street sweepers can only be used on large paved areas where access is available. (Street sweepers can also be used, with limited effectiveness, on open areas of frozen ground.) Hand brooms have some limited effectiveness for sweeping roofs.

Environmental impact from sweeping is limited to particulate resuspension.

(8-4) Mechanized Street Flushing

As is the case with mechanized street sweepers, street flushers have the advantage of a high rate of areal coverage, e.g., a few thousand square feet per minute per pass. A single pass typically removes 90 to 99 percent of the contaminant and a second pass typically results in more than 99 percent removal of the original amount of contaminant. Thus mechanized street flushers appear to be as effective as firehosing and faster. However, their use is limited to streets or other large paved areas.

Using mechanized street flushers poses the potential problem of flushing contaminants into the storm sewer system and thence into the sewage treatment plant or some other discharge point. If this is not desired, the runoff must be captured. Otherwise, there are no significant adverse ecological effects.

(8-5) Surface Removal Techniques

Firehosing, flushing with water, sweeping, and vacuuming do not usually have any significant effect on the building or paving surfaces which are being decontaminated. Another class of cleanup techniques for hard surfaces consists of removal of some of the surface to which the contamination adheres. Surface removal techniques would likely be applied only for residual contamination which cannot be removed by the nondestructive techniques. These techniques include removal of contaminated surfaces by chemicals, scraping or wirebrushing, sandblasting, or other abrasive techniques. Sandblasting, while very effective in removing contaminants from hard surfaces, poses the hazard of suspending contaminants in air unless preventive measures are taken.

Using surface removal techniques on artificial surfaces poses no significant ecological problems. Paint stripping requires the use of caustic chemicals, but the sludge will have to be collected in any case. Sandblasting is not a viable technique unless measures are taken to contain the particulate dust which would otherwise be resuspended in the air.

(8-6) Other Removal Methods

Other methods for removing contaminants from hard surfaces, primarily small areas, include wiping with tac-cloths or similar material, applying strippable films, and perhaps even ultrasonic cleaning. Strippable films and wiping are probably only effective on very smooth surfaces such as furniture tops or automobiles, but may have some application. Ultrasonic cleaning poses the possible hazard of resuspending small particulates.

(8-7) Containment

Containment techniques may be used (1) to temporarily immobilize contaminants onto hard surfaces while cleanup measures are being formulated, (2) as a long-term measure to seal off a contaminant from being a hazard, or (3) as a final step to seal off any residual radiation after cleanup measures have been completed. Containment techniques using an impervious sealant are 100 percent effective for reducing the hazard from alpha emitters since the external hazard from these radionuclides is negligible. However, the sealant must be maintained for as long as the underlying surface might be a hazard, to avoid a hazard when the sealant weathers or otherwise deteriorates. Paint, tar, oils, and liquid asphalts are the commonly known containment materials, based on 1950s and 1960s technology that was primarily concerned with nuclear weapon fallout. Many of the soil stabilizers shown in Table A-1 (Appendix A) could also be used to temporarily contain contaminants.

If the containment is temporary, solvents or other techniques are needed to remove the sealant to permit cleanup of the surface. (The sealant itself may be employed as a means of removing the contamination by "locking onto" the contaminant so that it is removed with the sealant.)

Applying techniques for containing contaminants in place on impervious surfaces and then perhaps removing the containing material may be costly in monetary terms and disruptive to human activities, but otherwise there is no significant effect on the environment.

9.5 RECOVERY AFTER CLEANUP

Most of the cleanup techniques for urban/suburban areas will not cause significant long-term ecological damage. Within a matter of months to a year or two following the destruction of vegetation, lawns and small plants could be reestablished. The only long-term impact would be the lack of large trees and shrubs, if they had to be removed.

Many of the treatments involving earthmoving, destruction of vegetation, or soil stabilization are commonly used in urban/suburban areas when preparing land for development.

9.6 QUANTITATIVE ASSESSMENT OF CLEANUP IMPACTS

Table 9-1 is an estimate of the relative impact on the ecology of an urban/suburban area as a result of applying the cleanup treatments described

Table 9-1. Relative rating of environmental impact of treatments on a scale of 0 (no impact) to 100 (greatest impact).

Treatment	Area Disturbed (km^2) 0.01	0.1	1.0	10.0	Assumptions
0-1 Natural Rehabilitation	---	---	---	---	Not acceptable treatment
1-1 Chemical Stabilization	0	0	0	0	
1-2 Remove Vegetation by Clear Cutting	0.07	0.7	7	70	
1-3 Remove Stumps and Grub Roots	0.075	0.75	7.5	75	
1-4 Surface Scraping and Grading (<5 cm)	0.025	0.25	2.5	25	
1-5 Shallow Plowing (<10 cm)	0.025	0.25	2.5	25	
1-6 Deep Plowing (10 to 40 cm)	0.05	0.5	5	50	
1-7 Soil Cover (<25 cm)	0.05	0.5	5	50	Assumes retaining walls around trees
1-8 Soil Burial (25 to 100 cm)	0.05	0.5	5	50	Assumes retaining walls around trees
2-1 Remove Plow Layer Soil (10 cm)	0.05	0.5	5	50	
2-2 Remove Shallow Root Zone Soil (<40 cm)	0.075	0.25	2.5	25	
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	0.05	0.5	5	50	
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	0.075	0.75	7.5	75	
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	0.025	0.25	2.5	25	
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	0.05	0.5	5	50	
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	0.075	0.75	7.5	75	
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize					
3-1 Barriers to Exclude People	0.01	0.1	1	10	Assumes short-term treatment
3-2 Barriers to Exclude Large Animals	0.01	0.1	1	10	Assumes short-term treatment
3-3 Barriers to Exclude Large and Small Animals	0.01	0.1	1	10	Assumes short-term treatment
4-1 Asphalt Hard-Surface Stabilization	0.1	1	10	100	
4-2 Concrete Hard-Surface Stabilization	0.1	1	10	100	
5-0 Sewage Sludge Application	0.01	0.1	1	10	Might not be socially acceptable
6-1 Washing (<3 mm)	0	0	0	0	
6-2 Flooding (3 to 30 cm)	0	0	0	0	Possible redistribution problem
7-0 Soil Amendments Added	0	0	0	0	
8-1 Washing with High-Pressure Water	0	0	0	0	Possible redistribution problem
8-2 Vacuuming	0	0	0	0	
8-3 Sweeping	0	0	0	0	
8-4 Mechanized Street Flushing	0	0	0	0	
8-5 Surface Removal Techniques	0	0	0	0	
8-6 Other Removal Techniques	0	0	0	0	
8-7 Containment	0	0	0	0	

in Section 9.4. The impacts are rated on a scale of 0 (no impact) to 100 (greatest impact) for the various treatments and the size of the area disturbed.

In the urban/suburban case impact is assumed to be directly proportional to the area affected, because there are relatively few wild animals, except those considered pests, to be displaced and the vegetation will be replaced rather than permitted to reestablish naturally. Therefore, the impact on a 10-km^2 area is assumed to be 1,000 times greater than the impact on the 0.01-km^2 area. This is in contrast to undeveloped land types where impact is not assumed to be directly proportional to the size of the area.

Treatments 4-1 and 4-2, stabilization with a hard surface, are judged to be the most severe with a rating of 100.* Not only will these treatments result in killing all vegetation and obviating most social and economic uses, but the surface remains in place for a significant time period, in contrast to the other treatments where the area can be restored to near its original condition within a few years.

Treatment 1-3, stumping and grubbing, and treatments 2-2, 2-5, and 2-8, removing the shallow root zone, are rated next in severity with a rating of 75. These treatments will result in the death of essentially all vegetation. Treatment 1-2, clear cut vegetation, is rated less damaging at 70 because some of the vegetation can propagate from existing root systems.

Treatments 1-7 and 1-8, soil cover; treatment 1-6, deep plowing; and treatments 2-1, 2-4, and 2-7, removing the plow layer, are judged roughly equivalent with a rating of 50. Most trees will not be seriously damaged or killed by these treatments, but all other vegetation will be destroyed. Treatments 1-4, 2-3, and 2-6, scraping and grading, and treatment 1-5, shallow plowing, are rated approximately equal with a rating of 25. Damage is to a lesser degree than with removal of the plow layer.

Treatments 3-1, 3-2, and 3-3, barriers to exclude people and animals, are assigned impact ratings of 10. Presumably the barriers are for a short time period. Application of sewage sludge may pose some problems in social unacceptability.

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*All ratings are for a 10 square km area.

Treatment 1-1, chemical stabilization, and treatments 8-1 through 8-7, treatment for artificial surfaces, are judged to have negligible environmental impact provided they are done correctly so that the contaminant is either contained or controlled in a desirable manner.

9.7 CONCLUSIONS

Although it may be very expensive and socially disruptive to clean up contamination from a large urban/suburban area, significant adverse effects on the natural ecology are short term. Many of the treatments are used during normal construction activities that occur in urban/suburban areas. Within a matter of months to a year or two following cleanup, lawns and small plants will be reestablished (except in the case of hard-surface stabilization). The only change will be the lack of large trees and shrubs if they have been removed. The consequences of not effectively cleaning up the contaminant (e.g., human health) may be more significant than concern for the environmental impact of cleanup treatments. Thus, environmental impacts must be secondary to selecting the most effective treatment or treatments. The residual contamination must be reduced to some acceptably low level; if this necessitates the complete destruction of all vegetation, that impact must be accepted. In this context there are no treatments that are unacceptable, except natural rehabilitation. Circumstances will dictate the most desirable treatments for a particular situation.

9.8 URBAN/SUBURBAN LAND AREAS REFERENCES

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PART III

WILDLIFE

CHAPTER 10, WILDLIFE

CHAPTER 10
WILDLIFE

10.1 OVERVIEW

A large amount of information must be integrated to describe which impacts to wildlife will occur in particular situations. For example, the time span over which impacts occur, the type of disturbance, land area, land types, vegetation component, wildlife component, and wildlife ecology all must be considered. In addition, feedback and interactions among these factors must be considered. So that this information can be more easily dealt with, several simplifications will be made. These include a standardization of the above variables. This is followed by a general discussion of characteristics which relate to impacts on each wildlife group of birds and mammals. This discussion is made first for immediate impacts, and then repeated for long-term effects.

The term "ecological impact" implies two basic actions. First, there is some disturbance to an area. Second, there is a reaction (impact) which results from the disturbance. Of interest are those impacts caused by human disturbance which result in a change in population numbers and/or species content of an area. Since impacts can be subtle or gross, only those impacts which are quantitatively measurable in the field are considered.

The impact on an area usually has short-term and long-term components. The short-term component can be measured immediately following the disturbance. The long-term component must be examined for duration as well as magnitude. Some criterion is needed to decide how much change is required to "recover" the disturbed area (i.e., the quality of the recovery), and how long the recovery will take. However, the product of the recovery can vary. If the land and vegetation return to a different condition, a new wildlife community may become established which is very different from the original one. Naturally, the rate of recovery will vary among land types and climates.

This raises the question of the location of the end point of the impact. Since "impact" is defined as a change, the end point is where changes become too small to measure quantitatively. However, natural environmental processes are dynamic; that is, they fluctuate constantly. When this fluctuation is slow the ecosystem is considered stable, or in equilibrium. Likewise, wildlife communities are only relatively stable. Thus it is both unreasonable and impossible to restore a community to its exact original condition. The practical solution is to restore the original natural conditions in land and vegetation as nearly as possible, and simulate recolonization of wildlife. A new, but somewhat different, wildlife community will become established in a dynamic equilibrium with the new and somewhat different habitat.

A broad range of human disturbances can result from the treatment of hazardous material spills. The least significant disturbance is probably surface scraping of a thin layer of ground. The impact of this to wildlife might be unmeasurable. Probably the greatest impact would result from defoliation of plant life, followed by covering the soil surface with cement or some other mechanical stabilizer. If done on the maximum area size, this treatment would cause immediate local extinction or emigration of the majority, if not all, of the wildlife in the area. It might also cause abnormally high population densities in areas contiguous to the treated area due to emigration.

In order to evaluate the impact of treatment disturbance in the different land types, a reference standard for "disturbance" is needed. This standard will be taken as the most drastic disturbance as described above. In this case the immediate impact is that which follows the treatment. The recovery phase is defined as following the erosion or removal of the ground covering. For simplicity this is assumed to be removed at one point in time. Less drastic treatments can be evaluated across the land types by using the same rationale applied on a lesser scale.

The impact to the local wildlife of a land treatment is heavily dependent on the land area that is disturbed. The areas of concern range from 0.01 km^2 to 10 km^2. These areas can be envisioned as squares: the smaller is 100 meters on a side and the larger is approximately 3.16 km on a side. Since a point-to-point discussion of this entire size range is impractical, these end points plus a midpoint area of 1 km^2 (1 km or 1000 meters on a side) will be discussed. An additional area 100 km^2 is also included because it approaches an upper "end point", at which a measurable impact can be expected for almost all wildlife species. These should typify the desired range of areas.

A wide variation in habitats exists for each land type under consideration. Again, some simplification is needed in order to organize the wide range of impacts. This can be done by using a procedure which has proved successful in plant ecology; i.e., describing a typical habitat type within each land type. The following is an adaptation of Whittaker's system[25] for this purpose:

- Deserts include a wide range of communities. It is appropriate to note that two types of desert occur in the United States: (1) warm-temperate deserts, represented by the widespread creosote bush communities and the floristically rich uplands of the Chihuahuan and Sonoran deserts, and (2) cool-temperate desert scrub, including the sagebrush semidesert of the Great Basin. The floras of both these desert types share a scrubby habitat. Also, in both a lack of moisture is critical to the maintenance of the various habitats. Thus deserts can be typified as those areas of extremely low annual rainfall.

- Prairie (or grassland) includes the great prairies, plains, and desert grasslands of the United States. Despite reduction of vegetation structure to a single major horizontal stratum, plant species diversity in grasslands can be high compared with most forests. These are areas of relatively low rainfall (but more than deserts) and experience a broad range in mild temperatures.

- Deciduous forests grow in moderately humid, continental, temperate zone climates, with summer rainfall and severe winters. Broad-leaved deciduous trees (oak, beech, maple, ash, basswood, etc.) are dominant in forests with trees 30 to 40 meters tall. Animal life of temperate deciduous forests is abundant but varies according to the season; diversity of plant and animal species is moderately low to moderately high. Deciduous forests are extensively developed in the eastern United States.

- Coniferous (evergreen) forests occur in varied temperate zone circumstances. Extensive needle-leaved evergreen forests occur in continental climates of the western United States, and in places where soil characteristics, or fire frequency, or both, favor pines over broad-leaved trees in the milder climate of the eastern United States. Coniferous forests are dominated by pine, fir, spruce, etc. A special type of coniferous forest is the subarctic-subalpine needle-leaved forest of the cold edge of the climatic range of forests. These areas exist in the northern part of North America and exist to the south at higher elevations in mountain areas.

- Mountain areas can be categorized as vertical extensions of other land types, as well as those areas which are exclusively non-forested aeolian or alpine regions. Aeolian mountain areas are almost never the sole habitat of animals using them. Therefore, wildlife responses detailed in the discussions of the other land types are applicable. When mountain areas are extensive, they may be very similar to tundra, and that land type should be referred to. The reader is referred to these specific sections for treatment of the wildlife of mountain habitats.

- Tundras are the treeless arctic plains. The vegetation forms are varied and there are often complex patterns of dominance by dwarf-shrubs, sedges and gresses, and mosses and lichens. In many tundras the deep layers of the soil are permanently frozen, and only the surface soil is thawed and becomes biologically active during the summer. In many of these communities, repeated freezing and thawing of the soil separates rocks from finer soil materials and arranges the rocks in parallel strips, or in networks with polygonal cells; striking internal patterning of the plant communities in relation to soil differences results. Vegetation cover decreases toward the sparse lichen communities, rock fields and ice of high elevations.

- Coastal inter-tidal marshland can be salt-water or estuarine. These areas, especially salt-water marshes, are extremely rich energy sources. Like prairies, they are limited in vertical structure. The plants of salt-water marshes are herb and forb-like. Marshes are not usually extensive, but are rather patchy in occurrence, or form a narrow band along a lake or coast.

- Agriculture is unique, being the substitution of a usually monotypic community for one or more natural plant communities. Agriculture is practiced in nearly all climates, although many hot and cold areas are not yet occupied fully. Agriculture can be characterized as managed fields with generally low vegetation (under 12 feet) dominated by 1 or 2 cultivated plant species. The most common secondary species are those generally considered "weeds," i.e., introduced herbs. Agriculture is extremely widespread in the United States except where climate and/or terrain are exceedingly harsh.

- Suburban land types are best described as those areas which make up areas of human habitation. Like agriculture, these areas are extremely widespread. The numerous roads and human activity associated with this land type severely restrict the type of wildlife which can exist. The human dwellings are usually associated with exotic introduced plants and/or weedy species. As with agriculture, this land type is an imposition of a new community upon a previous and older natural community. This favors a low number of species, but with high densities.

Some species have extremely low population numbers and must be examined individually to assess potential cleanup impact. Identification of these sensitive species can be obtained from Federal and State lists of threatened and endangered species.[5,22] State lists are to be preferred since they often include recent information on steps which have been taken to protect the species. State agencies also usually have recent literature and staff knowledge which may bear on the problem.

If a habitat which supports such a species is disturbed, several things may be done to speed up the recovery phase for the animal. This may be necessary for disturbances to rare species. For example, the Trumpeter Swan was close to extinction (about 65 birds) in 1935.[7] Areas where these birds breed were designated as off-limits to hunters. Also, additional food was made available at these sites in winter. Finally, the birds were introduced to other potential breeding sites. Due to these steps, the population had recovered (to about 915 in the U.S.) by 1976.[2] Other direct steps can be taken to accelerate faunal recovery, that is, increasing the rate of vegetative recovery.

Faunal recovery is strictly related to the recovery of the vegetation. The fauna cannot normally respond before the vegetation has done so. There are three components of the vegetation which are particularly important to animals. The first is the plant species which colonize a disturbed area. These are of especial importance to the herbivores. The other two components are vegetative height and density, i.e., the vegetational structure (see Emlen[9] for an exception). All three of the above components will change over time in the successional processes of the vegetation. Faunal recovery must, to some degree, be an upward process in terms of the food chain. Carnivores cannot colonize an area until their prey is available. Since abundances may increase slowly by reproduction, or quickly by invasion, it is difficult to predict a recovery for animals at the top of the food chain. However, these effects can be mitigated for those predators which can utilize a wide variety of prey, so that food can be caught during several stages of the vegetation succession.

Once vegetational succession has produced a new climax community, the more similar the new vegetation is to the original, the more similar the new fauna should be to the original fauna. This does not require a vegetation be established that is identical to the original. All that should be required is an approximation of the original vegetation which provi-es the same resource value in terms of food and structure. The critical questions to wildlife restoration are the "quality" and duration of vegetation recovery.

Plant succession has been well studied by plant ecologists[25] but the faunal community succession process which occurs in nature has not been studied as much. As plant succession occurs, multiple feedbacks are possibly among and within plants and animals (not to mention soil content changes, ground-level temperature regime cahnges, etc.). The network can be extremely complicated. However, faunal changes can be closely examined with respect to plant succession, and different animal species will show greater or lesser facility for recovery.

In most cases some species which were not among the original fauna of the area will move in during part of the vegetative recovery. These species will probably move out of the disturbed area as the habitat changes toward one more similar to the original one. This causes a decrease in species diversity as the climax of the faunal succession is reached. The pattern of plant species diversity in succession emerges as a rise from the start of recovery to a pre-climax peak, and then a leveling off at a slightly lower level as the dynamic equilibrium of the climax ensues.[8]

The few studies that have been done on faunal succession draw evidence from the fossil record and emphasize evolutionary (very long term) time. Of concern here is ecological, not geological, time, i.e., a relatively short period of time during which succession may occur, but evolution cannot.[19] Thus this discussion emphasizes the responses which are expected from individual species, rather than faunal succession.

10.2 EFFECTS ON BIRDS

Much information must be integrated in an examination of impacts on birds. Unfortunately, much of this information deals with particular species, making generalizations difficult. However, in order to understand impacts on birds some generalization is necessary, as a discussion of each species individually is impractical. Therefore, impacts are described for groupings of birds which share some general life history and/or feeding characteristics, or are closely related. These groupings are examined for short-term effects (immediate impacts) and long-term effects (recovery phase), then each land type is examined for specific short- and long-term effects.

Measurement of a change in the numbers, or population, of a bird species is not an easy or unambiguous process. First the term "population" must be defined in some way which is not necessarily land-area dependent. Once this is done a census method must be picked from those which have been shown to be accurate.[1,10] But even after a standard for measurement is chosen, and the data taken, it is still necessary to put the measured impact into context. What is really desired is the effect on the local species. This effect can only be ascertained by having a local wildlife expert analyze the data for the disturbed area and generalize the measured impact into an impact value based on local abundances.

10.2.1 Short-Term Effects

In general, a disturbance to an area will be much more serious to permanent residents than to migrators. This is especially true where the disturbed area is along a migration route. If adequate alternative routes of migration are available there may be no quantitative impact. Where only one route is possible, if food is not taken from the area by the migrants the impact may be very slight. However, once alternative routes of travel are used, it may prove very difficult to reintroduce the disturbed area as a part of the migration route. This will depend on how many of the migrators are lost, whether the alternative route is really as adequate as the original, and whether the route is learned or innately known. The slow rate of reintroduction of residents and migrants who feed on an area should be slightly greater for the more mobile migrant populations.

The seasonality of a disturbance is of extreme importance to birds. In general, disturbances in the spring will have a much greater initial impact than those in other seasons for two principal reasons. The first is that the breeding season occurs in the spring for most American bird species.[24] The second reason is that the spring is also a very critical time of growth for plants. Naturally, a disturbance in another season can affect spring conditions; however, most bird species can react to adverse habitat conditions before breeding occurs. For example, they may nest elsewhere, or at least nest in lower densities.

Among most birds, a disturbance to the breeding grounds is generally more serious than an equal disturbance to the wintering range. Many birds hold territories during the breeding season, but form flocks during the winter. Flocks can lose members to other flocks when food is scarce, or can remain cohesive at a small cost to each of the members. This is not true of the destruction of breeding territories. The area lost here will almost always result in a lower number of breeders. Thus an immediate impact is more likely to be of greater magnitude when breeding habitats are destroyed.

Some birds feed away from the nesting area or hold feeding territories around the nesting area. The nesting can be done in tightly packed colonies or, when food is taken at some distance away from the area of the nest, in looser aggregations. Those species which hold feeding-nesting territories are much more spaced out. Obviously, disturbance of a colonial breeding area will affect more birds than the same area disturbance to a feeding-nesting territory.

A strong correlation between body size and feeding-nesting territory size has been shown for many bird species.[20] Thus a disturbance of a given-sized area will usually affect more members of small species than larger ones. The loss of an area of 0.01 km^2 can cause the loss of six song sparrows' feeding-nesting territories. However, the same area is only 0.25 percent of a red-tailed hawk's feeding-nesting territory. A 1 km^2 area is roughly a quarter of the size of a red-tailed hawk's territory, and is a reasonably large area in terms of most smaller birds. In any case, there can be little doubt that the loss of an area of 100 km^2 from the breeding range of almost any species will have a measurable impact.

10.2.2 Long-Term Effects

Birds respond very quickly to habitat changes due to their high mobility. When the proper conditions prevail, bird dispersal is facilitated. However, different life histories will cause some differences. Size differences will also be critical, as larger birds can expand their territories more easily than smaller birds. The following differences also hold for some broad groups of birds.

In general, migrators being more mobile than permanent residents, will colonize areas more quickly. However, where migration routes and summer/winter grounds do not border on a suitable area, colonization can be much slower. Permanent residents have an advantage in being able to establish themselves at a time when migrators are not present. Some species, such as the Trumpeter Swan, can migrate or not, depending upon food resources, and will recover accordingly.

The area used for breeding grounds by migrators may spread at a somewhat more rapid rate than that of permanent residents. However, the choice of wintering grounds is likely to be even more flexible. The particular migratory species which uses an area will probably depend on the successional stage of the vegetation. Some species of migrators may colonize new breeding habitats more quickly than others. These effects may not have corresponding effects on the wintering range except for a change in the number of young present. However, since the breeding territories must be reestablished each year, complicated variable changes in the species pattern on the breeding grounds may occur. The damping of these changes may extend beyond the vegetative recovery phase.

Feeding flocks are apt to be rapid colonizers since their foraging method entails high mobility and allows them to exploit a thinly spread resource.[2] Birds with feeding territories usually colonize from a "leading edge" of the population. This movement is necessarily slower. The recruitment into flocks may be somewhat slower, by reproduction, so that even though a flock may use an area, the vegetation is not exploited to as great an extent as by the slower colonizing territorial species.

Competition among species may be important to recolonization. The first bird species to colonize an area can move in unopposed. However, the species which replace it in faunal succession may have to compete with the established species in the area. The net effect is one of prolonging the faunal successional process. Just how long the succession takes will therefore be somewhat dependent on the intensity and duration of the total amount of interspecies competition that occurs.

The following "trophic/niche" groups of birds contain families whose species share trophic level and lifestyle characteristics. Naturally, some families have members in more than one group. These families are divided into the respective groups in the following discussion. Examples of typical families are:

1. Large carnivorous birds: American vultures, buteo hawks (Accipiter family), and large owls.
2. Medium-sized carnivorous birds: medium-sized falcons, kites (Accipiter family), and medium-sized owls.
3. Small carnivorous birds: kestrels (Falcon family), shrikes, and small owls.
4. Large primarily herbivorous birds: grouse, pheasants, and turkeys.
5. Medium-sized primarily herbivorous birds: mockingbirds, thrashers, thrushes, blackbirds, and quail (Pheasant family).
6. Small primarily herbivorous birds: hummingbirds, titmice, and sparrows (i.e., almost all of the Fringillid family).
7. Medium-sized insectivorous birds: woodpeckers, tyrant flycatchers, and swallows.
8. Small insectivorous birds: wrens, vireos, and wood warblers.
9. All sized truly omnivorous birds: ducks, jays, crows, and gulls.
10. All sized aquatic feeder birds: plovers, sandpipers, and phalaropes.

Some land types take longer to restore than others. This can be considered the sensitivity of the land type to disturbance. The reasons for sensitivity can be the magnitude of the disturbance, the amount of vegetative structure, and climatic conditions present, the length of the growing season, the soil types present, and other factors. These many factors are integrated in the analysis of recovery of vegetation and land types over time. Here, differences in the responses of the bird faunas to the immediate disturbance and the subsequent recovery of the different land types are described.

Table 10-1 gives examples of bird species from each trophic/niche group in each land type which yield a measurable impact if the maximum disturbance has been made on the specified (or larger) land areas. The table uses area size differences among groups of birds to show how the groups are affected. This should not be equated with the qualitative "importance" of a species. For example, more robins would be lost than red-tailed hawks for a disturbance to a habitat for both. But the hawks may be more "important" than the robins in terms of numbers in existence or aesthetics.

The table assumes that at least ten breeding territories must be lost to a species before impact can be measured. No literature is available upon which to base an estimate of the number of breeding pairs which must be removed from a habitat to yield a measurable impact. The figure of ten was chosen because it represents a number at which large and/or uncommon species will begin to show a measurable impact. The figure of ten is thus a minimum. The real figure should be higher for many species. However, lower figures should seldom occur. A further assumption is made that measurement is solely on a local scale. Bird breeding territory area is used because the breeding grounds are of the greatest immediate importance to the multiplication (reproduction) of most populations. Bird breeding territories may vary with food resources in some cases. However, breeding area should generally be less variable than any other type of defended area used by individual birds.

10.2.2.1 Deserts--

The impact of a disturbance in deserts will be greatest for small herbivores, medium sized insectivores, and all carnivorous birds. An added impact on carnivores is the loss of a great diversity of reptilian

Table 10-1. Examples of bird species impacted by maximum disturbance to specified types and sizes of land areas.

MAJOR GROUPS	SIZE OF LAND AREA			
	0.01 km^2	1 km^2	10 km^2	100 km^2
1. LAND TYPE				
DESERT				
Large Carnivores				Red-tailed hawk
Medium Carnivores				Prairie falcon
Small Carnivores		Loggerhead shrike	Elf owl	
Small Herbivores		Black-throated sparrow		
Medium Insectivores		Ash-throated flycatcher		
PRAIRIE				
Large Carnivores				Golden eagle
Medium Carnivores				Prairie falcon
Small Carnivores			Sparrow hawk	
Large Herbivores		Greater prairie chicken		
Omnivores	Franklin's gull	Common crow		Common raven
DECIDUOUS FOREST				
Large Herbivores		Ruffled grouse		
Medium Herbivores		Baltimore oriole		
Small Herbivores		Black-capped chickadee		
Medium Insectivores	Least flycatcher	Acorn woodpecker		
Small Insectivores	White-eyed vireo	Tennessee warbler		
CONIFEROUS FOREST				
Small Herbivores		Pine siskin		
Medium Insectivores		Western flycatcher		
Small Insectivores		Olive warbler		
TUNDRA				
Large Herbivores		Willow ptarmigan		
Aquatic Feeders		Whimbrel		
COASTAL INTER-TIDAL				
Medium Herbivores		Yellow-headed blackbird		
Small Herbivores	Song sparrow	Marsh wrens		
Medium Insectivores	Bank swallow	Tree swallow		
Small Insectivores		Yellow-throat		
Omnivores		Pintail		
Aquatic Feeders		Willet		
2. LAND USES				
AGRICULTURE				
Large Carnivores			Barn owl	
Medium Carnivores			Burrowing owl	
Small Carnivores		Loggerhead shrike	Sparrow hawk	
Medium Herbivores	Robin	Mockingbird		
Small Herbivores	House sparrow	Chipping sparrow		
SUBURBAN				
Medium Herbivores	Cardinal[b]	Mockingbird		
Small Herbivores	Song sparrow	House finch		
Medium Insectivores	Cliff swallow	Black phoebe		
Omnivores		Blue jay		

[a] Territory sizes taken from Welty[24] and Schoener[20] or estimated from sizes of similar species. Species nomenclature follows Peterson,[18] where scientific names are also given.

[b] Member of the sparrow family.

prey. Large- and medium-sized herbivores occasionally occur in desert, usually on its fringes, as is true of most small insectivores and omnivores which live in or near deserts. The desert itself is not the sole habitat of these species, and impacts are thus lessened.

Resident desert bird faunas should contain a high proportion of specialist species which have low population densities. These birds will be extremely slow to respond to most recovery situations. The generalist species which do occur in desert can usually be expected to expand their numbers beyond the normal level upon colonizing a disturbed area. In this particular habitat the presence of generalists in abundance will probably further retard recolonization of specialists to a measurable degree. Management may be extremely useful in this unusual case.

10.2.2.2 Prairies--

Prairies are remarkable for having a distinct lack of vegetative height. Large herbivores and omnivores are the groups most impacted by a disturbance here. These are closely followed by carnivores of all sizes. Carnivores feed not only on bird prey on prairies, but also on the high populations of mammals which are common herbivores. Medium-sized and small herbivores, while not as diverse on prairies as in other land types, may still be very abundant. Once again, as smaller herbivores are examined, the impact of a disturbance is usually magnified. Medium-sized insectivores often feed over prairie, but seldom nest there. Thus the impact to this group should be reduced. Even less impact should be seen in aquatic feeders, who use prairie areas as stopping-feeding sites during migration.

Prairies contain an imbalance of generalist species, mainly due to the high carnivore and omnivore diversity. Thus the recoveries of prairie bird faunas are largely secondary effects, since both the above groups depend to some extent on animal prey. Carnivore recovery may lag far behind the vegetative recovery. The omnivores, on the other hand, are generalists and will recover more quickly. Much more omnivore feeding than breeding occurs in prairie areas, also facilitating the return of this group. The remaining breeding species are herbivores which are generally mobile species for their size. They will recover relatively quickly.

10.2.2.3 Deciduous Forests--

Deciduous forests have good diversity and abundance of herbivores and insectivores of all sizes. These groups will bear the major impact of a disturbance in most cases. Here also large and medium sized carnivores will occur mainly where there are breaks in the forest, and be impacted in proportion to the disturbed area of the forest breaks. Small carnivores and omnivores, while lacking in diversity in these forests, may be locally abundant. These last two groups should be widespread where they occur, thus lessening potential impacts upon them.

Deciduous forests are generally richer in bird fauna than coniferous forests and relatively higher proportions of specialist species occur. Thus, the faunal recovery will take longer in deciduous forests. However, these forests also have the advantage of being extensive, so colonists are available. These bird faunas may be extremely sensitive to disturbance, since the specialists may have a more "patchy" distribution as well as lower population densities. Because of their size and lesser mobility, the smaller herbivores and insectivores may be very slow in recolonization.

10.2.2.4 Coniferous Forests--

The disturbance of coniferous forests should impact small herbivores and insectivores of all sizes to the greatest degree. A great abundance and diversity of these groups occur here. In breaks in the forest, large and medium-sized carnivores occur and will be impacted where the breaks are disturbed. Coniferous forest supports relatively less small carnivores, large and medium-sized herbivores, and omnivore diversity. Where these groups occur, however, they may do so in abundance, and thus be impacted. Again, these last groups (except the small carnivores) are more likely to occur in breaks in the forest.

Coniferous forests tend to contain a relatively limited fauna compared with the other land types. However, the number of specialists and generalists is usually evenly balanced. Naturally, the generalists will respond to vegetative recovery more quickly. However, since coniferous forests are generally extensive, surrounding forest areas are almost always present to provide colonists. As vegetative recovery nears completion, more and more specialists will move in to supplement the labile generalists.

10.2.2.5 Aeolian Mountain Peaks--

A disturbance to a mountain-alpine habitat will affect only those few birds which have adapted to this barren land type. An example of one of the few species of birds which are specialized for this type of habitat are the Ptarmigans (in the Grouse family). During winter, alpine birds move to lower elevations, and live in other land types. Herbivores of all sizes will receive the greatest impact from an environmental disturbance, because of the disruption in their food supply. Large and medium sized carnivores may use alpine areas for hunting and breeding, but carnivores will be impacted to a lesser degree due to their ability to move into other types of habitat below treeline. The other trophic/niche bird groups should rarely occur in alpine areas and thus receive no impact from a disturbance to it.

Due to specialization of herbivorous alpine birds and the patchy and disconnected nature of the alpine habitat, recovery from a disturbance will be an arduous process. Mountains are to a large extent "islands" separated by a "sea" of forest;[25] therefore, recolonization of alpine areas may only be possible from within the original population. Many alpine birds winter in nearby forests, thus, the more isolated a mountain is, the longer it will take for colonists from other mountains to arrive. Since large and medium carnivores of alpine areas are generalists they will recover more quickly. However, they will only be able to recolonize alpine areas as their prey also recolonizes.

10.2.2.6 Tundra Areas--

The tundra is commonly only the summer range of species which breed there. However, a group of large herbivores (ptarmigans) are resident on tundra, and thus are subject to the greatest impact of any disturbance.

Impact on the principal summer breeding migrants, the aquatic feeders, is also very serious. Many of these birds nest in aggregation, so impacts are either drastic or considerably dampened, depending on the location of the disturbance. A few omnivores (gull species) share this characteristic and nest on or near tundra. Two large carnivores (the snowy owl and gyrfalcon) feed on tundra and breed nearby. These last two birds have large ranges which help to mitigate any impact upon them.

Tundra bird faunas are largely migratory, so that bird recovery can be relatively rapid. However, since the bulk of breeding for the aquatic feeders occurs here, the recovery of breeding populations must generally follow the recovery of food resources. The yearly freezing of the ground does not encourage invertebrates, so that more vegetation must be eaten. The only resident birds, the large herbivorous ptarmigans, are also closely tied to vegetative recovery. Where tundra occurs it is usually extensive, so that the bird fauna can recolonize an area easily.

10.2.2.7 Coastal Inter-Tidal Marshlands--

Marshlands are usually rich energy sources[25] and therefore all non-carnivorous groups except large herbivores are usually represented. The small insectivores and aquatic feeders are especially noticeable, the former even more so in fresh-water marshlands. Since those species which live in marshes are often restricted to it, they will be impacted severely by a disturbance. Large- and medium-sized carnivores which frequent marshes usually include other areas in their hunting range, or can easily do so. They are therefore less impacted. Many aquatic feeders and omnivores use marshland as stopping and/or feeding places during migration, and can be subjected to a lesser impact by changing their migration routes.

Marshland bird species are generally very sensitive in terms of faunal recovery. A very high relative proportion of specialists occurs here. Their recovery is complicated by the patches in which this habitat occurs. If the disturbance occurs over an entire patch of marshland, recovery will be much slower than that expected for a disturbed area within a patch. Thus, disturbed area size effects are especially important. Size effects will be greatly magnified for smaller birds, but may have relatively little significance for the more mobile large- and medium-sized carnivores.

10.2.3 Land Uses

10.2.3.1 Agricultural Areas--

Agricultural areas contain either breeding or feeding areas for some members of all the trophic/niche groups except small insectivores. However, the groups which are most impacted by disturbance of agriculture are the medium and small herbivores and the carnivores of all sizes which prey upon them. Large herbivores, medium insectivores, and omnivores are more likely to feed on agricultural areas than to breed on them, and will usually be less heavily impacted. Aquatic feeders are the least likely group to be impacted since they occur only under special conditions (excess water or ponds available). However, the impact on this group increases if they can breed where an area is disturbed, again a special case.

Agricultural land mainly supports generalist type bird species (i.e., those with a broad niche). This land type has not existed long enough for specialists (birds with a narrow niche) to evolve necessary adaptations for habitat specialization. The few specialists found here were preadapted to some special feature of the agricultural habitat, and moved in from other habitats. The result is an extremely resilient bird fauna. This fauna will follow vegetative recovery very closely. Since the species which occur in agricultural areas have dense populations, dispersal from surrounding populations should send almost constant waves of colonizers into the disturbed area.

A second alternative for agricultural land is to allow it to revert to a state more similar to its preagricultural condition. In this case the agricultural condition can be considered an additional disturbance from which the avifauna must recover. In order to evaluate this particular type of recovery, the sections dealing with the preagricultural land type should be consulted. Differences from these land type recoveries should not vary greatly due to the agricultural use of the land. The avifauna will change from an agricultural one to one commensurate with the particular land type's plant succession.

10.2.3.2 Suburban Areas--

Suburban birds are generally birds which were preadapted to live with humans. This implies a versatile lifestyle and a broad niche. The groups which would be impacted (about equally) by a disturbance are medium and small herbivores, medium-sized insectivores, and omnivores. Groups which occur on the fringes of suburban areas are large carnivores, large herbivores, small insectivores, and aquatic feeders. These will be lightly impacted by a suburban disturbance, if at all.

Suburban bird faunas will also respond quickly in recovery of a disturbed area. Evidence for this is abundant in almost any spreading city. A heavy proportion of generalists exists in most suburban habitats.[9] In addition, rather dense populations usually occur.[12] These areas are usually extensive or at least connected by corridors such as freeways, construction sites, and/or rural human populations. Thus colonization can be extreme during the recovery of the land type. In addition, the recovery of many species need not be tied to vegetation recovery since human dwellings provide structural diversity, and may provide food.

As in the agricultural land use, the alternative of allowing the suburban area to succeed to something more like the presuburban land type exists. However, this process is complicated by the presence of semipermanent structures (e.g., buildings) which increase bird habitat heterogeneity. Without these structures a recovery similar to that described in the appropriate land type is possible. However, if suburban land is simply deserted, species which depend on suburban structures for nesting and/or roosting (or cover from predators) will be favored. These will generally not be the species commonly found in the presuburban land type, and recovery will be retarded.

10.3 EFFECTS ON MAMMALS

The impacts on mammals, like birds, can be described by examining mammals in groups which share similar lifestyles and feeding habits, as well as in groups which are closely related. The general characteristics shared by these various groups will first be examined for short-term (impact) effects, and then for long-term (recovery phase) effects. Then each land type is examined for the specific characteristics which relate to the mammal fauna for short- and long-term effects.

There are two types of classification of mammal living areas: the defended territory, and the total area traveled in by an animal during its daily activities (excluding migration routes), or "home range." The latter area is of concern in a discussion of impacts since it is probably closer to the area size necessary for survival. However, it may only be an approximation of the area which is essential. In some cases mammals form aggregates, or colonies. These colonies usually have a home range, but impacts are difficult to assess. The loss of an area of habitat can cause either the loss of a colony, or only the loss of some of the colonial individuals. There are little data with which to even begin to examine these measurement problems. However, several methods of varying accuracy do exist which can be used for the estimation of mammal home range.[21]

10.3.1 Short-Term Effects

The impacts to mammals which share similar size and trophic level, or trophic/niche group, are generally consistent. Therefore the following groups are defined, with examples of the mammalian families which are representative of the groups.[4]

1. Large carnivorous mammals: wolves and mountain lions.
2. Medium-sized carnivorous mammals: foxes and small cats.
3. Small carnivorous mammals: skunks and weasels.
4. Large primarily herbivorous mammals: wild boar; deer; pronghorn; and bison, goats, and sheep.
5. Small primarily herbivorous mammals: 10 rodent families, pikas, and hares and rabbits.
6. Large omnivorous mammals: bears.

7. Small omnivorous mammals: opossums, raccoons, ringtails, and armadillos.
8. Insectivorous mammals: shrews and moles.
9. Flying mammals: two bat families.

10.3.1.1 Large Carnivores--

The primary immediate impact of a land disturbance to the large carnivores should be negligible for the range of area sizes under consideration. An area of 100 km^2 is equivalent to only about one to six mountain lion home ranges.[23] Due to the wide ranging of these cats, even a much larger disturbance would be very hard to measure in terms of a change in population numbers. However, a secondary impact to this animal is the loss of its prey. Again this effect is probably unmeasurable, since the deer they feed on are also large animals which are widely distributed.

A slightly different situation exists for the other large carnivore group, the wolves. Measurement of populations is extremely difficult, even for the exceedingly common coyote. But in addition to measurement problems, the grey (timber) wolf also forms packs. A disturbance to the 100 km^2 area size could eliminate (from the area) a minimum size pack of two, but this area is only about one-tenth the home range of a pack of eight,[23] so that primary impacts are impossible to assess. Some attempt can be made to measure the change in pack size as an indication of impact, but this is an extremely variable characteristic. Again, secondary impacts are possible, but they are unlikely to be measurable. In all large mammalian species emigration is the most likely cause of a drop in population numbers after a disturbance.

10.3.1.2 Medium-Sized Carnivores--

Impacts on medium-sized carnivores are also difficult to measure. Once again, the maximum disturbance to the maximum area size specified (10 km^2) for consideration should not produce a measurable impact in most cases. The major prey of these carnivores, small herbivorous birds and mammals, will be impacted at some area size, so that it may be possible to get some measure of secondary impacts. The medium-sized carnivores are not as mobile as the large carnivores, so that it may be possible to estimate an impact in some cases for a disturbed area size of 100 km^2.

10.3.1.3 Small Carnivores--

Many of the small carnivorous mammals are nocturnal, and thus ignored by the majority of humans. However, it is in this group that impacts in the larger area sizes can be measured. Weasels will have measurable impacts where pre-cleanup prey densities are either high, or are moderate but extensive in area. The other small carnivores have larger home ranges in general and will be much harder to examine. Secondary (prey) effects need not be examined for the groups which have measurable impacts, since these effects are included in the change in population size.

10.3.1.4 Large Herbivores--

With the large herbivores size of the cleanup area again becomes important. This difficulty is compounded by the ability of most large herbivores to change home ranges seasonally (by migration). Local changes in population size can probably be measured for disturbances of the 100 km^2 area size. However, these changes will probably be measurable only immediately, for the high mobility of the larger herbivores will soon reduce the possibility of finding many of the animals which reside in the area, since they may leave it or perish. Animals which successfully leave the area are not defined as being impacted.

10.3.1.5 Small Herbivores--

Small herbivores are generally restricted to living their entire lives in relatively small areas. The once popular idea that some small mammal herbivores migrate has been thoroughly disproved.[13,14] These animals are the most important United States mammals in terms of species diversity and abundance. Their populations are easily sampled and monitored in most cases. In addition, they form an important link between primary producers (plants) and the carnivores which depend on them for food.[11]

Table 10-2 gives examples of small herbivorous mammal species that occur in each land type which yield a measurable impact if the maximum disturbance has been made on the specified (or larger) land areas and types. The table indicates the kind of rodents and lagomorphs (the rabbit order) which occur in the various land types and the general disturbed area sizes which will produce impacts. The density of these animals is relatively easy to measure.

Table 10-2 assumes that at least 12 to 15 home ranges must be lost in an area before a local impact can be measured. As in the bird section, this home range (area) amount is a minimum for measurable impact, except for large and/or uncommon mammals. A special case of vole and lemming home ranges being very small is somewhat counteracted by their exceptional movement abilities, so that a larger area must be disturbed for these species than just 15 home ranges. Home range size usually varies with changes in the density of food resources. Special cases in specific locations are to be expected to vary from the predictions of the table.

It may be that small herbivore species can be used as indicators to measure the effects of various disturbances. Small herbivore species can change at the onset of a disturbance.[16] As succession ensues, changes in species composition and density can also occur.[16] When the original species distribution and density reoccur, an advanced stage of recovery has probably been entered. A distinction must be made, however, between those small rodent species considered "pests," or those deemed undesirable by man, and species which are more beneficial to man's interests. Pest species are generally exterminated periodically where they exist near humans and impacts on them, although measurable, may not be of real concern.

10.3.1.6 Large Omnivores--

Large omnivores (bears) are another group for which it is exceedingly difficult to measure impacts. Only three bear species occur within the designated land types in North America. These will not be measurably impacted for disturbances to the land area sizes under consideration. For example, even without the problems of impact measurement, the 100 km^2

Table 10-2. Examples of small herbivorous mammals impacted by maximum disturbance to specified types and sizes of land areas.[a]

MAJOR GROUPS	SIZE OF LAND AREA[b]	
	0.1 km^2	1 km^2
LAND TYPE		
Desert	Cactus mouse	Antelope squirrels Kangaroo rats Wood rats Jackrabbits
Prairie	Pocket gophers Pocket mouse Harvest mouse Grass voles Jumping mouse	Ground squirrels Prairie dogs Jackrabbits
Deciduous Forest	Deer mouse	Tree squirrels Flying squirrels Chipmunks Cottontail rabbits
Coniferous Forest	Deer mouse Phenacomys Redback voles	Marmots Tree squirrels Flying squirrels Chipmunks
Tundra	Lemmings Tundra redback vole	Showshoe hare
LAND USE		
Agriculture	House mouse[c] Pocket gophers[c] Cotton rats[c]	Ground squirrels[c] Jackrabbits[c]
Suburban	Black rat[c] Norway rat[c] House mouse[c]	

[a] Home range sizes taken from McNab,[17] Vaughn,[23] and Burt and Grossenheider,[4] or estimated from home range sizes of similar species. Nomenclature of the genera and species follows Burt and Grossenheider,[4] where scientific names are also given.

[b] For land areas of 0.01 km^2 or less no small mammal herbivore should be impacted, above 1 km^2 all should be impacted.

[c] Denotes pest species or genera.

area size is only about half the size of the Grizzly bear home range.[23] However, the actual effects on these animals can be serious since they are restricted to isolated patches of wilderness areas,[4] and emigration may not always be possible.

10.3.1.7 Small Omnivores--

The impacts from disturbance of the larger area sizes may be measurable for the small omnivores. These animals are generally nocturnal and occur in areas which are human-disturbed (mainly agricultural). Impacts should be easier to measure for opossums, and more difficult to measure for the wider ranging raccoons.[17] These animals are widely distributed where they occur, so that immediate impacts are difficult to measure due to a reassortment of individuals during movement away from the disturbed area.

10.3.1.8 Insectivores--

Insectivores are small mammals with extremely limited mobility. Like small rodents, they are closely tied to their area of residence and can be expected to be measurably impacted in disturbances to all but the smallest land area sizes. In addition, these animals depend on insect and other small animal prey, so that a disturbance to the prey can cause as great an impact as a direct disturbance to the insectivores themselves.

10.3.1.9 Flying Mammals--

The impact from a disturbance on the flying mammals (bats) is roughly comparable to that on insectivorous birds. These nocturnal animals have excellent mobility, but are most sensitive to disturbances to breeding areas. In addition, many bat species are colonial, so the breeding areas are patchy in occurrence. A disturbance of the smallest designated area size could have a measurable impact on a breeding colony. On the other hand, much larger feeding areas would have to be disturbed to yield a measurable impact. Bat species occur in several types of land areas.

10.3.2 Long-Term Effects

The recovery phase of a mammal community is closely tied to the recovery of the vegetation. The food value of the vegetation is an important determinant in mammal recovery. In addition, the amount of cover provided by the vegetation is important to small mammals which are subject to avian predators. The vertical height of the vegetation is actually of less general importance since relatively fewer mammals are canopy dwellers than ground dwellers. The main benefit provided by the vegetation height is the amount of feed which exists at each level for herbivores and omnivores. Another extremely important benefit for some prey species is cover.[6] Naturally, the habitat beneath the vegetation should vary with vegetative height and density. Therefore an important indirect benefit is provided.

10.3.2.1 Large Carnivores--

Large carnivores will respond to the recovery of their prey following a disturbance. The functional response of carnivores, an increase in the exploitation of prey, can be practically instantaneous. However, the numerical response, an increase in the number of predators in an area, is necessarily slower. This response can occur both through immigration or large carnivores to the recovering area[15] and by reproduction, but the latter process is much slower and may be masked by immigration. Since large carnivores are not measurably impacted by a disturbance, their recovery in an area will be a qualitative rather than a quantitative change. Qualitative changes can be measured, but only on a very restricted local scale, so that the measurements are of questionable significance in assessing impacts to the individuals of highly mobile species. The pertinent point is that the quality of the local area changes when the animals leave.

10.3.2.2 Medium-Sized Carnivores--

The recovery of medium-sized carnivores should share the same characteristics as the recovery of large carnivores, but on a more local scale. Since medium-sized carnivores have less mobility, they will be slower in responding to prey in the interior of a large disturbed area.

However, the numerical response will still be made mainly by immigration. Again, population changes of these animals will be limited by changes in the populations of their prey. The medium-sized carnivores are also unlikely to be impacted measurably, so that recovery will only be a qualitative process.

10.3.2.3 Small Carnivores--

Disturbances to the larger land area sizes will have measurable impacts on the small carnivores, and therefore "recovery" can be demonstrated quantitatively. Since these carnivores are less mobile than the larger classes, much of the numerical response must come from reproduction. Small carnivores should follow fluctuations in prey density much more closely than larger carnivores due to their more limited mobility.

10.3.2.4 Large Herbivores--

For large herbivores, size effects are again of critical importance in evaluating recovery from a disturbance and their recovery will be qualitative rather than a measurable change. Since the large herbivores are highly mobile (some are migratory), the rate of movement back into an area will depend on the reestablishment of edible vegetation. The number of large herbivores that a disturbed area can support will change gradually, and some disturbed areas may actually support higher densities than originally existed. This will occur where the plant food is actually denser and/or of better quality during recovery than in the climax community.

10.3.2.5 Small Herbivores--

The recovery phase of small herbivore populations can be extremely complex.[3,12] Interspecies competition effects will be important in many cases.[12] The recovery of small herbivore numbers should depend on both immigration and reproduction. Small mammals are noted for their ability to respond reproductively, but dispersal abilities can also play a key role in their population dynamics.[11] The recovery of small herbivores should be very closely tied to changes in the vegetation, and several distinct successional communities may occur.

The immediate disturbance to an area may well create ideal conditions for invasion by small "pest" rodents. These animals may aid plant succession by cycling nutrients in the community and thus provide a beneficial function.[11] However, competition may occur among "natural" species attempting to immigrate and could have a very detrimental effect. Careful management of small mammals can provide means for facilitating community recovery. Predators can be introduced to dampen outbreaks in small herbivore populations, if control measures are needed. Small mammal populations can provide an index for monitoring community recovery of both the flora and fauna.

10.3.2.6 Large Omnivores--

Because of their great mobility and large home range sizes, the recovery of large omnivores (bears) after a disturbance to an area is, like that of other large animals, a qualitative process. The recovery of bears is most likely to consist of them simply using the area to forage and/or den in again. The problem of range reduction is a serious one for North American bear species. Therefore real recovery may be very difficult if the maximum area size disturbance causes the loss of one or both of a breeding pair which live in an isolated patch of habitat. This problem will rarely occur, however, and can be overcome by introduction of one or more outside individuals as appropriate.

10.3.2.7 Small Omnivores--

The small omnivorous mammals are for the most part opportunistic species. Both the opossum and raccoon are familiar species which have managed to survive in areas of human disturbance due to their versatile feeding abilities. The armadillo has actually extended its range of occurrence in the Southwestern United States during the last hundred years.[23] Quantitative recovery of these species should occur closely in pace with changes in both vegetation and prey species on the largest-size area. These species are reasonably mobile and can probably spread as well by immigration as by reproduction.

10.3.2.8 Insectivores--

Insectivore recovery will depend on the recovery of insectivorous prey, which in turn will probably depend largely on vegetative recovery. Thus the return of insectivores to a disturbed area is a second-order effect and will require a longer time lag than that which will occur for the similarly impacted small rodents. The recovery of moles will be stimulated where macroinvertebrates are added to the soil to assist vegetative recovery. Few insectivores breed more than twice a year, and many breed but once. This will tend to retard recovery, as reproduction is an essential part of colonization due to the animal's limited mobility.

10.3.2.9 Flying Mammals--

The recovery of bats after a disturbance to an area will vary with the nature of the disturbance. Like many birds, bats require the reestablishment of vertical structure in the vegetation. However, several bat species roost in dead trees, so that available roosts may actually increase from a disturbance. Bats are commonly known for their mobility. Several species migrate seasonally, or nightly, to food sources. For these reasons, bat recovery can occur rapidly after recovery of insect prey in feeding habitats, and densities may actually increase given the proper circumstances. Changes in bat populations will usually be due to emigration and immigration rather than reproduction.

10.3.3 Land Types

Table 10-3 gives examples of mammal species other than small herbivores from each trophic/niche group in each land type which are measurably impacted if the maximum disturbance has been made to the specified land areas. Large mammal groups are extremely mobile, and are therefore impacted only by area sizes greater than 100 km^2. Many of the species occur in more than one land type. This phenomenon is more evident in this table than it is for birds (Table 10-1) and small herbivorous mammals (Table 10-2). The greater body size and mobility of many of the mammal species may be the reason for this. Again, the number of home ranges lost is used in estimating the types of species lost when a given size area is disturbed.

Table 10-3. Examples of mammals other than small herbivores impacted by maximum disturbances to specified types and sizes of land areas.[a]

	SIZE OF LAND AREA			
MAJOR GROUPS	0.1 km^2	1 km^2	10 km^2	>100 km^2
1. LAND TYPE				
DESERT				
Large Carnivores				Mountain lion
Medium Carnivores				Kit fox
Small Carnivores			Hognose skunk	
Large Herbivores				Mule deer
Bats	Yuma myotis[b]			
PRAIRIE				
Large Carnivores				Coyote
Medium Carnivores				Red fox
Small Carnivores			Spotted skunk	
Large Herbivores				Pronghorn
Small Omnivores			Opossum	
Insectivores	Vagrant shrew			
DECIDUOUS FOREST				
Large Carnivores				Mountain lion
Medium Carnivores				Lynx
Small Carnivores			Long-tail weasel	Marten
Large Herbivores				Whitetail deer
Large Omnivores				Black bear
Small Omnivores		Armadillo	Opossum	Raccoon
Insectivores	Pacific mole			
Bats	Little brown myotis[b]			
CONIFEROUS FOREST				
Large Carnivores				Grey wolf
Medium Carnivores				Lynx
Small Carnivores		Least weasel	Short-tail weasel	Marten
Large Herbivores				Mule deer
Large Omnivores				Grizzly bear
Small Omnivores			Opossum	Raccoon
Insectivores	Shorttail shrew			
Bats	Mexican freetail bat[b]			
TUNDRA				
Large Carnivores				Grey wolf
Medium Carnivores				Arctic fox
Small Carnivores		Least weasel	Short-tail weasel	
Large Herbivores				Barren ground caribou
Large Omnivores				Grizzly bear
2. LAND USES				
AGRICULTURE				
Medium Carnivores				Red fox
Small Carnivores			Spotted skunk	
Large Herbivores				Mule deer
Small Omnivores			Opossum	Raccoon
Insectivores	Eastern mole			
Bats	Evening bat[b]			
SUBURBAN				
Small Omnivores			Opossum	Raccoon
Bats	Pallid bat[b]			

[a] Home range sizes taken from McNab,[17] Vaughn,[23] and Burt and Grossenheider,[4] or estimated from home range sizes of similar species. Nomenclature of the genera and species follows Burt and Grossenheider,[4] where scientific names are also given.

[b] Bats, although migratory, appear in the smallest area category because of their colonial or semicolonial nesting characteristics.

Impacts can be defined more precisely as smaller mammals are examined, due to their reduced mobility which smaller size usually causes. Therefore, in the discussion of the mammal fauna, small mammals are emphasized. In addition, some land types, notably agricultural and suburban, support more "pest" specimens than others. A special consideration regarding these land types is the desirability of restoring these mammals.

10.3.3.1 Deserts--

The single most important and prevalent group of mammals in the desert habitat is the small herbivores. Although large, medium, and small carnivores, large herbivores, and bats may occur in deserts, their diversity does not approach that of the small herbivores. When a desert area is disturbed, some measure of the impact on small mammals is often obtainable. However, the impact must be inferred from a comparison of the disturbed area with some nearby area. The return of herbivores will keep pace with the vegetation return, a distinctly slow process. Deserts are continuous, so that colonization by both dispersal and reproduction can occur from the edges of the disturbed area. Intermediate faunal communities are not expected for succession in most desert disturbances.

10.3.3.2 Prairies--

The prairie habitat supports a diversity of large herbovores. Carnivores of all sizes as well as small omnivores may occur here, but by far the most abundant and diverse group in prairies is the small herbivores. The importance of small herbivores in this habitat is greater than in any other habitat except tundra, where their importance is roughly equal.[12] A disturbance to prairie will certainly have a measurable impact on some small herbivores for all but the smallest area size. Therefore some measurement of the recovery may be possible. The recovery of the small herbivores may involve changes in the densities and distributions of the species present, as the vegetation changes. The community recovery in this habitat can be relatively rapid. The continuous nature of prairies should aid in this process.

10.3.3.3 Deciduous Forests--

Deciduous forests follow a pattern of response similar to coniferous forests, but with some important differences. These forests can be expected to be somewhat richer in their mammal fauna. The seasonal change in canopy cover allows a richer understory of forage for both large and small herbivores. Bats and insectivores occur here, but are seldom a major component of the fauna. Medium size carnivores and small omnivores should occur more frequently in deciduous forests. The response of the mammal fauna to a disturbance may again involve the movement of large mammals out of the area, and an increase in small herbivores. In comparison to forests, the importance of small mammals will be greater than in nonintensive agriculture during the recovery; but in the mature forest, small mammals will have a similar importance to that in nonintensive agriculture.[11]

10.3.3.4 Coniferous Forests--

In coniferous forests during the recovery cycle following a disturbance the number of small mammals will probably increase rather than decrease. Large mammals (carnivores, herbivores, and omnivores) will usually leave the area, at least until restoration is well under way, and then return. Thus in coniferous forest, impacts are very difficult to measure but recovery is easier to assess. This habitat is ideal for the use of small mammals as indicators of recovery.

Bats and insectivores are relatively unimportant components of the mammal fauna, though they do occur in coniferous forest. If insectivores are present they may feed on insects which attack the dominant trees, and thus increase their importance. The medium carnivores and small omnivores are more likely to occur at the forest border, and thus will recolonize from other habitats. The continuity of coniferous forests should help most species recolonize from undisturbed areas.

10.3.3.5 Tundra Areas--

In tundra, small herbivores are key species to the ecosystem economy.[10] Small carnivores depend upon these herbivores for prey.

Large herbivores, large omnivores, and large and medium carnivores may also occur seasonally in tundra. A disturbance to tundra will certainly impact the small mammals measurably in most years. The well known cyclic fluctuations in population size of the dominant herbivores may cause an inability to measure immediate impact in some years. However, the recovery phase measurements of following years will show the impact belatedly. Tundra is extremely sensitive to disturbance and a long period of time is required for the vegetation to recover. Whether the recovery of the tundra habitat and fauna is possible in ecological time is questionable, and predictions about recovery cannot be made.

10.3.3.6 Coastal Inter-Tidal Marshlands--

The marshlands are not expected to support extensive mammal faunas.

10.3.4 Land Uses

10.3.4.1 Agricultural Areas--

Herbivorous species are generally detrimental to man's interests where they occur in agricultural areas. The most common pests are, of course, the small herbivores. However, as the intensity of agriculture increases, the role of small herbivores decreases.[10] The other trophic/niche groups are less frequent in occurrence in agriculture, but small omnivores and medium-sized and small carnivores are considered pests where animal husbandry is involved. Large omnivores and carnivores should occur only rarely. Farm buildings are usually excellent places for bat "nursery" breeding places, so that their occurrence in agriculture areas may be relatively high. Insectivores are a relatively unimportant, though occurring, component of the mammal fauna here.

The recovery of mammals, particularly small herbivores, on disturbed agricultural land can be extremely rapid. Most, if not all, of the responding animals will be pest species. Most recovery problems will involve having too many animals, at least in density, rather than too few. Some beneficial effects may result from nutrient cycling through small herbivores. However, these benefits are minimal because of the control that man can exert on the nutrient balance.

Here again, another alternative exists of allowing succession to something similar to the preagricultural land type. This is best thought of by considering agriculture as an additional disturbance to the treatment under consideration. The mammal recovery will be similar to the recovery described for the specific preagriculture land type, except where precluded by fencing. Fences which restrict large mammal access will not greatly retard recovery, but may have subtle effects. For example, if predators are excluded, prey species may be affected. A fence which excludes all ground-moving mammals will eliminate the recovery for all mammals except bats, and in some cases squirrels.

10.3.4.2 Suburban Areas--

The suburban habitat, much like agriculture, is typified by pest species. No large mammals of any type and no carnivores of any size occur regularly in this habitat. Small omnivores, small herbivores, and bats make up the rather depauperate mammal fauna of the suburban habitat. The small omnivores have principal habitat elsewhere, and the easily measurable impact to small herbivores is probably not of concern. Feral domestic species, especially cats, may be impacted. Again this is probably not of concern. What may be very important, however, is the increase in rodent pests, and the diseases they carry, during the recovery. Introduction of predators such as feral cats may be the best technique for managing these outbreaks. The importance of mammals in suburban faunas is likely to be quite low, perhaps on a par with intensive agriculture.

If the suburban land use is abandoned, succession to a land type similar to the presuburban one may occur. However, the rate and quality of this recovery will depend on whether man-made structures remain or not. As in agriculture, this land use itself may be considered a disturbance. Fencing out large mammals will simply cause the loss of these animals as participants in the recovery. However, fencing out all ground-moving mammals may also fence surviving pest species in. These pests may require control measures to avoid health hazards to humans which might periodically occur in the fenced area.

10.4 CONCLUSIONS

The impact of a disturbance to a species was carefully defined at the beginning of the wildlife section, but many people may simply want to know if the disturbance will have a significant impact on the wildlife species. This demands not only a definition of impact, but also an evaluation of impact significance. If significance is defined as whether or not a disturbance puts any species in danger of becoming extinct, for the vast majority of wildlife species and the designated land areas the answer is "no".

The real concern must be for those species so small in numbers that extinction is a danger to them. These species fill the rare, threatened, and endangered species lists.[5,22] Many of these species are nearly extinct due to man's encroachment upon their habitats. Other species may be on the way to extinction with or without man's help. These two classes of endangered species may be difficult to tell apart. Whether or not species which are becoming extinct should be preserved is a social decision. This decision, conscious or unconscious, will govern their fate.

Many sensitive species may not be recoverable after a disturbance to their range. Other sensitive species may require expenditure of a great effort in order to assure their revival. This must be decided upon in each case where an endangered species is affected, presumably on the basis of the social and political values which predominate at the time of the disturbance. Any effort directed to this end may also have a fringe benefit of aiding in the recovery of the total floral and/or faunal community.

Table 10-4 rates the relative impacts on wildlife, immediately after cleanup, of the maximum disturbance possible in the individual treatment categories in each land type for the stated area sizes. Impacts on mammal and bird wildlife are scaled from 0 (no measurable impact) to 5 (elimination of most original species) for each combination of the three axes of land type, treatment, and area size with the exception of fencing, which divides impacts on mammals and birds.

Table 10-4. Relative impacts of land cleanup treatments on wildlife following maximum possible land disturbance.

MAJOR GROUPS	TREATMENT	TREATMENT NUMBER[a]	RELATIVE IMPACTS FOR DIFFERENT AREA SIZES (in km^2)[b]				
			0.01	0.10	1.0	10	100
LAND TYPE							
Desert	Stabilization, asphalt	4-0	3	4	5	5	5
	Vegetation removal	1	1	2	3	4	5
	Soil removal, stabilization	2	2	4	5	5	5
	Fencing (mammals only)	3-2	0	1	2	1	0
	Fencing (birds only)	3-2	0	0	0	0	1
Prairie	Vegetation removal	1	1	2	3	4	4
	Soil removal, stabilization	2	2	3	4	5	5
	Fencing (mammals only)	3-2	0	1	2	2	1
	Fencing (birds only)	3-3	0	0	0	1	1
Deciduous Forest	Stabilization, asphalt	4-0	2	4	5	5	5
	Vegetation removal	1	1	1	2	3	3
	Soil removal, stabilization	2	2	3	4	5	5
	Fencing (mammals only)	3-2	0	1	2	1	0
	Fencing (birds only)	3-3	0	0	0	1	1
Coniferous Forest	Stabilization, asphalt	4-0	2	4	5	5	5
	Vegetation removal	1	1	1	2	2	3
	Soil removal, stabilization	2	2	3	4	5	5
	Fencing (mammals only)	3-2	0	1	2	1	0
	Fencing (birds only)	3-3	0	0	0	1	1
Mountains (Alpine)	Vegetation removal	4-0	3	4	5	5	5
	Soil removal, stabilization	1	3	4	5	5	5
	Fencing (mammals only)	2	1	2	3	2	1
	Fencing (birds)	3-2	0	0	0	1	1
	Flooding	3-3	0	0	0	0	0
Tundra	Vegetation removal	1	3	4	5	5	5
	Soil removal, stabilization	2	3	4	5	5	5
	Fencing (mammals only)	3-2	1	2	3	2	1
	Fencing (birds only)	3-3	0	0	0	1	1
Coastal Inter-Tidal	Vegetation removal	1	3	4	5	5	5
	Soil removal, stabilization	2	3	4	5	5	5
	Fencing (birds only)	3-3	0	1	1	1	1
LAND USES							
Agriculture	Stabilization, asphalt	4-0	2	4	5	5	5
	Vegetation removal	1	2	2	3	4	5
	Soil removal, stabilization	2	1	1	2	3	3
	Sludge application	5-0	0	0	1	2	2
	Fencing (mammals only)	3-2	0	1	2	1	1
	Fencing (birds only), soil additive	3-3	0	0	0	1	1
Suburban	Stabilization, asphalt	4-0	1	2	3	4	5
	Vegetation removal	1	0	1	2	3	4
	Soil removal, stabilization	2	0	1	1	2	2
	Fencing (mammals only)	3-2	0	0	1	0	0
	Fencing (birds only)	3-3	0	0	0	0	0

[a] Treatment number 1 implies treatments 1-2 through 1-8, in general.

Treatment number 2 implies treatments 2-1 through 2-8, in general.

[b] Relative impact, based on reduction in biomass

0 - No measurable impact on species, < 5 percent reduction
1 - 5 to 35 percent reduction
2 - 35 to 60 percent reduction
3 - 60 to 80 percent reduction
4 - 80 to 90 percent reduction
5 - Original species eliminated, > 90 percent reduction

The assignment of the values of the table is a subjective process which necessarily assumes that all wildlife responds homogeneously to the disturbance. Although such an assumption is unrealistic, the table still provides insights toward the truth, i.e., reasonable estimates of how a wildlife community responds to a disturbance. The table can also be viewed as a ranking of treatments within each land type and area size.

Table 10-5 estimates the relative time for recovery of wildlife from the maximum disturbance possible and the individual treatment categories of each land type for the stated area sizes. The relative time to recovery is scaled from 0 (about one year) to 5 (2 or 3 centuries). The one-year period is required as a baseline to measure whether a community has changed to a greater degree than would be expected under "natural" conditions. The 5 rating puts recovery sufficiently far into the future that it is not reasonable to consider that recovery can take place, since evolution may change the community before it reaches equilibrium.

One major assumption has been made in the derivation of relative impacts: that is, the colonization rate must remain constant for all species in the successional process. While this is not true in most individual cases, it may be true on the average. That is, the species in the colonization process may have varying movement rates. But if the rates do not vary widely, then violating the assumption may not be very serious. The mathematical reasoning implies a linear relationship between area size and recovery time. The constant colonization rate assumption is actually another form of this assumption.

Wildlife is dependent on vegetative recovery; in fact, it is not reasonable to try to uncouple these two types of recovery. Therefore, Table 10-5 includes biases which are a direct result of considering the total environment in which the wildlife lives. These biases are necessary in order to improve the accuracy of impact assessment, and the computation of recovery times.

Table 10-5. Relative time for recovery of wildlife following maximum disturbance to land and cleanup treatment.

MAJOR GROUPS	TREATMENT	TREATMENT[a] NUMBER	RELATIVE TIME FOR RECOVERY FOR DIFFERENT AREA SIZES (in km^2)[b]				
			0.01	0.10	1.0	10	100
LAND TYPE							
Desert	Stabilization, asphalt	4-0	5	5	5	5	5
	Vegetation removal	1	2	2	3	4	4
	Soil removal, stabilization	2	3	4	5	5	5
	Fencing (mammals only)	3-2	2	1	1	0	0
	Fencing (birds only)	3-3	0	0	0	0	0
Prairie	Vegetation removal	1	1	1	2	2	2
	Soil removal, stabilization	2	1	2	3	4	4
	Fencing (mammals only)	3-2	2	1	1	0	0
	Fencing (birds only)	3-3	0	0	0	0	0
Deciduous Forest	Stabilization, asphalt	4-0	4	5	5	5	5
	Vegetation removal	1	2	2	3	3	3
	Soil removal, stabilization	2	2	3	4	5	5
	Fencing (mammals only)	3-2	2	1	1	0	0
	Fencing (birds only)	3-3	0	0	0	0	0
Coniferous Forest	Stabilization, asphalt	4-0	4	5	5	5	5
	Vegetation removal	1	2	2	3	3	3
	Soil removal, stabilization	2	2	3	4	5	5
	Fencing (mammals only)	3-2	2	1	1	0	0
	Fencing (birds only)	3-3	0	0	0	0	0
Mountains (Alpine)	Vegetation removal	4-0	3	4	5	5	5
	Soil removal, stabilization	1	3	3	4	5	5
	Fencing (mammals only)	2	2	1	1	0	0
	Fencing (birds only)	3-2	0	0	0	0	0
	Flooding	3-3	0	0	0	0	0
Tundra	Vegetation removal	1	3	4	5	5	5
	Soil removal, stabilization	2	3	3	4	5	5
	Fencing (mammals only)	3-2	2	1	1	0	0
	Fencing (birds only)	3-3	0	0	0	0	0
Coastal Inter-Tidal	Vegetation removal	1	1	2	3	4	4
	Soil removal, stabilization	2	1	1	2	2	2
	Fencing (birds only)	3-3	0	0	0	0	0
LAND USES							
Agriculture	Stabilization, asphalt	4-0	4	5	5	5	5
	Vegetation removal	1	1	1	1	1	1
	Soil removal, stabilization	2	1	1	1	1	1
	Sludge application	5-0	1	1	1	1	1
	Fencing (mammals only)	3-2	1	1	0	0	0
	Fencing (birds only), soil additive	3-3	0	0	0	0	0
Suburban	Stabilization, asphalt	4-0	3	4	5	5	5
	Vegetation removal	1	1	2	2	3	3
	Soil removal, stabilization	2	1	1	1	2	2
	Fencing (mammals only)	3-2	1	1	0	0	0
	Fencing (birds only)	3-3	0	0	0	0	0

[a] Treatment number 1 implies treatments 1-2 through 1-8, in general.
Treatment number 2 implies treatments 2-1 through 2-8, in general.

[b] 0 - < 1 year
1 - 1 to 3 years
2 - 3 to 5 years
3 - 5 to 50 years
4 - 50 to 100 years
5 - > 100 years

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PART IV

APPENDICES

APPENDIX A, STABILIZERS
APPENDIX B, IMPACT ASSESSMENT
APPENDIX C, LAND TYPES
APPENDIX D, CLEANUP TREATMENTS
APPENDIX E, GLOSSARY

APPENDIX A
STABILIZERS

A.1 INTRODUCTION

This appendix contains a brief description of the major categories of soil stabilizers, the subgroupings of stabilizers, and the values assigned to the stabilizer subgroupings, land types, and land-use classes given in Table A-1. The use of Table A-1 is also explained.

A.2 TYPES OF STABILIZERS

For purposes of this report, "soil stabilizers" are defined and categorized to determine their practical application to soil stabilization with the land types defined herein. Stabilizers are generally classified into three major categories according to Ingles and Metcalf:[1] chemical, mechanical, and physical. A fourth category, chemical with mechanical characteristics, is also considered here.

Individual stabilizers are shown at the top of Table A-1. The major category of each is shown by a symbol underneath in one of the first two horizontal rows; these rows additionally denote whether the stabilizer is organic or inorganic. The stabilizers listed in Table A-1 are listed in Table A-2 with information on manufacturers provided for those that have patented name.

A.2.1 Chemical

These stabilizers are liquid or solid additives to soil that effectively alter the physical properties of the soil being treated.

A.2.2 Mechanical

These stabilizers mechanically provide sufficient stability to bare soils to retard and/or prevent soil erosion caused primarily by wind and water,

SOIL STABILIZERS

TYPES OF STABILIZERS:
- ○ Chemical
- ● Mechanical
- ◆ Physical
- ⊙ Chemical with mechanical characteristics

Soil stabilizer	Stabilizer groupings: organic	Stabilizer groupings: inorganic	hazard level	application	durability	vegetation recovery	Land types: desert	Land types: prairie	Land types: deciduous forest	Land types: coniferous forest	Land types: mountain	Land types: tundra	Land types: coastal inter-tidal	Land use class: agriculture	Land use class: suburban
4-ter Butyl Pyrocatechol	○		2	2	1	3	b	a	a	a	a	b	b	a	b
Aerospray 52 (resin/water emulsion)	⊙		1	3	3	1	b	a	b	b	b	c	c	b	b
Agri-mulch (63 percent asphalt)		⊙	1	3	3	1	b	b	b	b	b	c	c	b	b
Anionic Asphalt Emulsion		●	1	3	2	2	a	b	b	b	b	c	c	b	b
Aquatain (sodium polypectate/glycerin/ammonia)	⊙		2	3	3	2	b	b	b	b	b	b	b	a	b
Asphalts Emulsions ... General Class		●	1	3	2	3	a	b	b	b	b	b	c	b	b
Asphalt-Plastic-Asphalt-Chipcoat		●	1	3	1	3	c	c	c	c	c	c	c	c	a
Bentonite	●		1	4	1	4	c	c	c	c	c	b	c	c	a
Calcium Sulfite/Calcium Chloride		●	2	3	2	3	c	c	c	c	c	b	b	c	b
Carboxymethyl Cellulose	⊙		2	3	3	2	b	a	a	a	a	b	a	a	a
Conerex (resin/water emulsion)	⊙		2	3	3	2	b	a	a	a	a	a	a	a	b
CMC-7-L (Sodium carboxymethyl cellulose, low viscosity)	⊙		2	3	3	2	b	a	a	a	a	a	a	a	b
CMC-7-M (Sodium carboxymethyl cellulose, medium viscosity)	⊙		2	3	3	2	b	a	a	a	a	a	a	a	b
CMC-7-H (Sodium carboxymethyl cellulose, high viscosity)	⊙		2	3	3	2	b	a	a	a	a	a	a	a	b
Curasol AE (polyvinyl acetate copolymer emulsion)		⊙	1	3	3	2	b	a	a	a	a	a	a	a	b
Curasol AH (high-polymer synthetic resin dispersion)		⊙	1	3	3	2	b	a	a	a	a	a	a	a	a
DCA-70 (water dispersible polyvinyl acetate emulsion)		⊙	2	3	3	2	b	a	a	a	a	a	a	a	a
Dialkyl Quaternary Ammonium Chloride		○	2	2	2	3	c	c	c	c	c	b	b	c	a
E802 Corn Extract, Mazofern Brand (corn steep water: N.P.Ca.Mg)	⊙		2	3	3	2	b	a	a	a	a	a	a	a	b
Electro-osmosis and electrohardening		◆	3	4	1	4	d	c	c	c	c	c	c	c	b
Elvanol 50-42 (polyvinyl alcohol)		○	2	3	3	2	a	a	a	a	a	b	b	b	b
Elvanol 71-30 (polyvinyl alcohol)		○	2	3	3	2	a	a	a	a	a	b	b	b	b
"Experimental" (styrene-butadiene emulsion in mineral oil)		○	2	1	3	2	b	a	a	a	a	c	b	b	b
Fatty Amine Acetate		○	2	4	3	2	c	b	b	b	b	c	c	b	a
Foams: e.g. polystyrene		●	2	3	1	3	c	c	c	c	c	a	a	c	b
Gantrez An-119 (polymeric anhydride)		⊙	2	3	3	2	b	a	b	b	b	b	b	a	b
Gantrez ES-335I (monoester resin)		⊙	2	3	3	1	b	a	a	a	a	b	b	a	b
Geon 652 (vinylchloride-vinylidene chloride latex)		⊙	2	3	3	2	b	a	b	b	b	b	b	a	b
Geotech (GTS 1104, GTS 1105, GTS U-58)		○	2	3	3	2	b	a	b	b	b	b	b	a	b
Goodrite 2570 X1 (styrene-butadiene latex)		⊙	2	3	3	2	b	a	b	b	b	b	b	a	b
Grouting		●	1	4	1	4	c	b	c	c	c	a	b	c	a
Gypsum Hemihydrate	●		2	3	2	3	c	b	b	b	b	b	c	b	c
Hydrofluoric acid		○	4	2	2	4	d	c	c	c	c	c	c	c	b
Krilium		○	2	3	2	3	b	c	c	c	c	b	c	c	a
Lignins		○	2	3	2	3	b	a	a	b	b	a	a	b	b
Meshes		●	1	1	2	4	a	b	c	c	c	c	c	b	b
Metallic soaps		●	2	2	2	3	c	b	c	c	c	b	c	c	b
NC 1556L (modified polyacrylamide)		○	2	2	3	1	b	a	a	a	a	b	b	a	b
Oil/Latex polymer emulsion		○	1	3	3	2	a	a	b	b	b	a	b	b	a
ORTHO soil mulch (asphalt emulsion)		●	1	3	3	1	a	a	a	a	a	a	b	a	a
paraffin wax		●	2	2	3	2	a	a	a	a	a	a	a	a	a
Petroset SB (rubber emulsion)		⊙	1	3	3	2	a	a	b	b	b	b	a	a	c
Phosphoric acid and Phosphates		○	2	2	2	3	b	b	c	c	c	b	b	b	b
Polyacrylamides (PAA)		○	2	2	3	2	a	a	a	a	a	b	b	a	b
Polyco 2460 (styrene-butadiene copolymer)		○	2	2	3	2	b	a	b	b	b	b	b	a	b
Polyco 2605 (vinylchloride-vinylidene chloride copolymer)		⊙	2	2	3	2	b	a	b	b	b	b	b	a	b
Polyethylene, vinyl, butyl rubber, and other impervious membranes		●	1	1	2	2	a	a	a	a	a	a	a	a	b
Polyvinyl alcohol		○	2	2	2	3	b	a	b	b	b	b	b	a	b
Quaternary ammonium salts: e.g. Cetyl trimethyl ammonium bromide		⊙	2	2	2	3	c	c	c	c	c	b	b	c	b
Resin adhesive Z-3876 (mainly polyvinyl alcohol)		○	2	3	3	3	a	a	b	b	b	b	b	a	b
Resins and polymers ... General class		○	2	3	3	2	a	a	b	b	b	b	b	a	a
road oil		●	1	3	2	3	b	b	b	b	b	b	c	b	a
rubberized asphalts		●	1	3	2	4	b	b	b	b	b	b	b	b	b
SBR Latex S-2105 (styrene-butadiene latex)		●	2	1	3	2	b	a	b	b	b	b	b	a	b
SEPARAN NP-10 (polyacrylamide, high molecular weight)		○	2	2	3	2	b	a	a	a	a	b	b	a	b
soda ash		○	2	3	2	3	c	b	b	b	b	b	c	b	a
sodium chloride		●	1	3	2	3	c	b	c	c	c	b	b	b	a
Sodium hydroxide (caustic soda; a compaction aid)		●	4	2	2	3	d	b	c	c	c	c	c	b	b
Sodium methyl siliconate		○	2	3	2	3	c	b	c	c	c	b	c	b	b
Sodium polyphosphate		○	2	2	2	3	c	b	c	c	c	c	c	b	b
Sodium rosinate		○	2	2	2	3	c	b	c	c	a	c	c	b	b
SOILGARD (elastomeric polymer)		⊙	1	3	3	2	a	a	a	a	a	b	b	a	b
Soil seal ("Formulation of copolymers")		⊙	2	3	3	2	a	a	a	a	a	b	b	a	b
Sulphonates and Lignosulphonates (compaction aids)		●	2	2	2	3	a	c	c	c	c	c	c	c	b
TACSS or Mitsui Stopper (Class of polyurethane monomers)	○		2	2	2	3	b	b	b	b	b	b	b	b	a
Technical Protein Colloid I-V	⊙		1	3	3	1	b	a	a	a	a	b	b	a	a
Technical Protein Colloid 5-V	⊙		1	3	3	1	b	a	a	a	a	b	b	a	b
Technical Protein Colloid 2236	⊙		1	3	3	1	b	a	a	a	a	b	b	a	b
Technical Protein Colloid 2260	⊙		1	3	3	1	b	a	a	a	a	b	b	a	b
Thermal stabilization		◆	3	4	1	4	c	c	c	c	a	a	b	c	b
Volclay	●		1	4	1	4	d	a	c	c	c	b	a	c	a
WICALOID Latex 7035 (AD) (carboxylated styrene-butadiene latex)		●	2	2	3	2	b	a	b	a	a	b	b	a	b

KEY TO RATINGS OF STABILIZER GROUPINGS

Hazard level	Application	Durability	Vegetation recovery
1 safe	1 manual - normal	1 permanent	1 immediate, natural
2 handling precautions required	2 manual - difficult	2 intermediate	2 requires seeding, normal response
3 adverse environmental effects	3 equipment - normal	3 short-term, 1 year or less	3 complete new seedbed required
4 highly hazardous	4 equipment - specialized		4 no recovery

KEY TO RATINGS

Land types and class
- a preferred
- b acceptable as a alternative
- c not acceptable, last resort measure
- d not applicable

without modifying the physical properties of that soil. The process consists primarily of compacting soils to a density that rejects water. It also includes hard surface materials, manufactured soil retention materials, and chemical aids to compaction.

Materials used for mechanical stabilization of soils include, but are not limited to, hard surface paving such as concrete and bituminous surfaces. Other manufactured materials are meshes, polyvinyl films, and erosion control nettings. Materials such as burlap bags with concrete, sandbags, rip-rap, and cribbing are also means of mechanical stabilization.

Other forms of this type of stabilizer include the use of grouts, sand, and other filler compounds that can be used to physically fill voids in the soil by absorbing water and swelling to seal off the surface area from water infiltration.

Equipment used for mechanical soil stabilization is divided into two types: (1) compaction equipment such as pneumatic-tired rollers, tandem rollers, sheepsfoot rollers, vibratory rollers, vibratory packers; and (2) application equipment such as concrete pavers, asphalt pavers, rock spreaders, distributors, and sprayers.

A third subcategory of equipment also should be considered for mechanical stabilization of contaminated areas. This includes equipment such as bulldozers, turn-a-pulls, and scrapers which are used to construct diversion channels, ditches, berms, and retention basins around the affected area. (These structures would be temporary to collect, divert, or retard surface drainage from adjacent areas or to prevent water from leaving affected areas and causing downstream contamination.)

A.2.3 Physical

These stabilizers stabilize soils by modifying their physical properties with heat, electricity, and cold.

A.2.4 Chemical with Mechanical Characteristics

This term applies to stabilizers that are chemically produced or chemical compounds that bind surface soils for short periods of time. Primarily, they are compounds used by the agricultural industry to promote germination and then break down once germination has begun. They are not true "mechanical" stabilizers because of their lack of relative permanency, and because there are brief periods between application and stabilization during which chemical reaction with soil occurs.

A.3 STABILIZER GROUPINGS

The four categories of stabilizers can be further categorized into groupings. These groupings define the physical characteristics and treatment types to promote "prescription-type" treatment of affected areas within the land types defined in the report. These groupings are shown at the left of Table A-1, separated by broken lines. To determine the rating of a grouping category for a particular stabilizer, use the number immediately above the broken line for the grouping category. The key to these number ratings is at the bottom of Table A-1.

The following definitions are provided for the groupings of soil stabilizers:

Organic and Inorganic — the category given to stabilizers that generally define the physical composition of the specific material.

Hazard Levels — primarily the degree of safety with which a stabilizer can be handled by personnel during the application periods. It also includes the "environmental safety" of the material after application.

Application — the method or procedure of applying the prescribed stabilizer to a defined area as it relates to available normal application equipment and methods.

Durability — the ability of a chemical or mechanical stabilizer to maintain a specified treatment for a prescribed time period. This includes the ability of a specified stabilizer to withstand the effects of the seasonal environmental changes.

Vegetation Recovery Period — the ability of a chemical or mechanical stabilizer to disintegrate in the normal revegetation process where localized natural seed sources are present (does not include conventional reseeding methods).

A.4 RATINGS OF STABILIZER GROUPINGS

The ratings of the stabilizer groupings noted on Table A-1 are defined as follows:

1, Safe — a material or technique that is generally harmless to the applicator, environment, and equipment.

2, Handling Precautions Required — requires compliance with manufacturers instructions for physical applications during handling, mixing, applying, and temperature extremes.

3, Adverse Environmental Effects — materials where there is no opportunity for the area to recover from the use of a stabilizer without major rehabilitation operations. It does not include consideration as a toxic substance to man.

4, Highly Hazardous — materials or techniques where the "cure" is more dangerous than the "disease." However, these can be situations where highly specialized personnel can be called upon to perform this type of stabilization.

A.4.1 Application

1, Manual (normal) — hand-operated equipment that can be used effectively and is frequently available to the home gardner.

2, Manual (difficult) — stabilizers that must be applied to a small area, are caustic to operators and equipment, have difficulty staying in solution, require difficult or specialized mixing techniques, or require special carrier substances for proper application.

3, Equipment (normal) — can be applied to large affected areas using standard agricultural or construction equipment; restricted to areas where there is space for the equipment to be used effectively.

4, Equipment (specialized) — requires specially manufactured equipment for proper application or standard equipment greatly modified to accommodate the stabilizer to be used.

A.4.2 Durability

1, Permanent — will remain in place without radical physical change as a result of normal climatic conditions. This includes the use of chemical stabilizers that permanently change surface soil characteristics. Any alteration of an area where this stabilizer is used would require major construction.

2, Intermediate — broad terminology meaning that natural recovery will eventually take place. This also applies to stabilizers that persist for at least 5 years when considered for surface applications. These same stabilizers can persist for periods of more than 5 years when incorporated into a compacted soil.

3, Short Term (1 year or less) — stabilizers that effectively control soil movement resulting from normal rainfall. It also includes stabilizers generally accepted in the agricultural industry as erosion retardents during germination periods of most crops.

A.4.3 Vegetation Recovery

1, Immediate (natural) — stabilizers which have little resistance to climatic conditions, and which permit natural invader plants to germinate and grow on disturbed areas.

2, Requires Seeding (normal response) — effectively hold surface soils intact for a period of at least 6 months, providing the applied membrane is not disturbed. Revegetation requires normal seedbed preparation and planting of selected varieties. Residues of these stabilizers, after they are incorporated, are biodegradable and have no effect upon the new seedlings.

3, Complete New Seedbed Required — stabilizers that were used must be completely removed or buried at sufficient depth with new "cold soil" so that an affected area can provide suitable growing conditions for vegetative reestablishment.

4, No Recovery — change the physical makeup of the surface soil sufficiently so that the plant zone cannot subsequently support any type of vegetation, and the stabilizer is not effectively altered by normal freeze and thaw conditions.

A.5 LAND TYPES AND LAND USE CLASSES

The seven land types and two land use classes discussed in this report are shown at the right of Table A-1, separated by solid lines. To determine the rating of each stabilizer on each land type or land-use class, use the letter above the solid line for the particular land type or class. The key to these letters (ratings) is located at the bottom of Table A-1. Each of these ratings is defined as follows.

a, Preferred — materials that are short-term effective, generally environmentally safe naturally and sociologically, and subject to the general moisture and climatic conditions of a land type.

b, Acceptable as an Alternate — basically the same characteristics as those classified "preferred," however, because of the effectiveness of the material or application procedures they should not be considered exclusively for stabilization of affected areas.

c, Not Acceptable (last resort measure) — materials that should not be used because of the resultant damage, primarily to the natural environment. When there are situations where the natural environment cannot be protected from irreversible effects of "accidental spillage," these materials may be used. This assignment is also made to materials when applied to various land types because of the variability within the land types themselves. For example, "prairies" can be divided into many types of "prairie" and a particular stabilizer can be effective for one of these "prairie" types without serious environmental damage. In other "prairies," however, this same stabilizer would produce irreversible effects and must not be used. Based upon this type of comparison with each of the land types, the "not acceptable" assignment is made where there is an irretrievable commitment of the natural resources present.

d, Not Applicable — materials that cannot be applied because of soil conditions, temperature extremes, or moisture conditions.

A.6 APPENDIX A REFERENCE

1. Ingles, O.G., and J.B. Metcalf. Soil Stabilization Principles and Practice. J. Wiley & Sons, New York—Toronto, 1973. 374 pp.

Table A-2. Manufacturer and application information for soil stabilizers.

STABILIZER	MANUFACTURER	APPLICATION RATE	REFERENCE
4-ter Butyl Pyrocatechol	---	---	Ingles & Metcalf
Aerospray^R 52 Binder (resin/water emulsion)	American Cynamid Co.	---	---
Agri-mulch (63% asphalt)	Douglas Oil Co.	1 liter per sq. meter surface	---
Anionic Asphalt Emulsion	Phillips Petroleum Co.	Surface - 2.25 liters per sq. meter	---
Aquatain (sodium polypectate/glycerin ammonia)	Larutan Corp.	Mix with soil	---
Asphalt Emulsions		2.0 liters per sq. meter, surface applied	
Asphalt (1 liter)-Plastic Asphalt (1 liter)-Chipcoat	---	14 kg per sq. meter applied phasing & compaction required	---
Bentonite	American Colloid, Inc.	---	---
Calcium Sulfate/Calcium Chloride	Dow Chemical Co.	2% by weight incorporated into upper 0.15 meter	---
Carboxymethyl Cellulose	Hercules, Inc.	Incorporate into soil surface	---
Coherex (resin/water emulsion)	Golden Bear Oil Co.	Incorporate into soil surface	---
CMC-7-L (sodium carboxymethyl cellulose, low viscosity)	Hercules, Inc.	Incorporate into soil surface	---

(continued)

Table A-2. (continued)

STABILIZER	MANUFACTURER	APPLICATION RATE	REFERENCE
CMC-7-M (sodium carboxymethyl cellulose, medium viscosity)	Hercules, Inc.	Incorporate into soil surface	---
CMC-7-H (sodium carboxymethyl cellulose, high viscosity)	Hercules, Inc.	Incorporate into soil surface	---
Curasol^R AE (polyvinyl acetate copolymer emulsion)	American Hoechst Co.	Incorporate into soil surface	---
Curasol^R AH (high polymer synthetic resin dispersion)	American Hoechst Co.	Incorporate into soil surface	---
DCA-70 (water dispersible polyvinyl acetate emulsion)	Union Carbide Corp.	Incorporate into soil surface	---
Dialkyl Quaternary Ammonium Chloride	---	3% by weight incorporated upper 0.15 meter	---
E802 Corn Extract, Maxofern Brand (corn steep water; N, P, Ca, Mg)	Corn Products Sales, Inc.	Incorporate into soil surface	---
Electro-osmosis and Electrohardening	---	---	Ingles & Metcalf
Elvanol 50-42 (polyvinyl alcohol)	E. I. Dupont de Nemours & Co., Inc.	---	---
"Experimental" (styrene-butadiene emulsion in mineral oil)	Ashland Chemical Co.	Surface 1.5 liter/sq. meter	---

(continued)

Table A-2. (continued)

STABILIZER	MANUFACTURER	APPLICATION RATE	REFERENCE
Fatty Amine Acetate	---	100% surface applied, approx. 1 liter per sq. meter	---
Foams (e.g., polystyrene)	---	100% surface applied	---
Gantrez An-119 (polymeric anhydride)	General Analine & Film Corp.	Incorporate into soil surface	---
Gantrez ES-3351 (monoester resin)	General Analine & Film Corp.	Incorporate into soil surface	---
Geon 652 (vinylchloride-vinylidene chloride latex)	B. F. Goodrich Chemical Co.	---	---
Goodrite 2570 X1 (styrene-butadiene latex)	B. F. Goodrich Chemical Co.	---	---
Grouting	---	---	Ingles & Metcalf
Gypsum Hemihydrate	National Gypsum Co.	---	---
Hydrofluoric Acid	---	3% solution incorporated into upper 0.15 meter	---
Krilium	Monsanto Chemical Co.	---	---
Lignins	---	6% by weight incorporated into upper 0.15 meter	---
Meshes	---	100% cover of disturbed areas	---

(continued)

Table A-2. (continued)

STABILIZER	MANUFACTURER	APPLICATION RATE	REFERENCE
Metallic Soaps	---	100% disturbed areas, spray	---
NC 1556L (modified polyacrylamide)	Dow Chemical Co.	---	---
Oil/Latex Polymer Emulsion	B. F. Goodrich Chemical Co.	---	---
Ortho Soil Mulch (asphalt emulsion)	Chevron Chemical Co.	---	---
Paraffin Wax	---	1/8 inch film over entire area	---
Petroset^R SB (rubber emulsion)	Phillips Petroleum Co.	---	---
Phosphoric Acid and Phosphates	---	7% aqueous solution	---
Polyacrylamides (PAA)	Dow Chemical Co.	---	---
Polyco 2460 (styrene-butadiene copolymer)	Bordon Chemical Co.	---	---
Polyco 2605 (vinylchloride-vinylidene chloride copolymer)	Bordon Chemical Co.	---	---
Polyethylene, Vinyl, Butyl Rubber, and Other Impervious Membranes	---	Total cover with 1% overlap of joints, pinned	---
Polyvinyl Alcohol	Swift & Co.	---	---

(continued)

Table A-2. (continued)

STABILIZER	MANUFACTURER	APPLICATION RATE	REFERENCE
Quaternary Ammonium Salts (e.g., Cetyl trimethyl ammonium bromide)	Dow Chemical Co.	---	---
Resin Adhesive Z-3876 (mainly polyvinyl alcohol)	Swift & Co.	---	---
Road Oil	---	2.25 liters per sq. meter, surface applied	---
Rubberized Asphalt	---	1.0 liter per sq. meter, surface applied	---
SBR Latex S-2105 (styrene-butadiene latex)	Shell Chemical Co.	Surface applied	---
SEPARAN NP-10 (polyacrylamide, high molecular weight)	Dow Chemical Co.	---	---
Soda Ash	---	7% by weight, incorporated into upper 0.15 meter	---
Sodium Chloride	---	4% by weight, incorporated into upper 0.15 meter	---
Sodium Hydroxide (caustic soda; a compaction aid)	---	3% minimum by weight to surface; 2% by weight when incorporated 6 inches deep	---
Sodium Methyl Silanolate	---	3% by weight incorporated into upper 0.15 meter; spray applied	---

(continued)

Table A-2. (continued)

STABILIZER	MANUFACTURER	APPLICATION RATE	REFERENCE
Sodium Polyphosphate	---	15% by weight incorporated into upper 0.15 meter	---
Sodium Rosinate	---	5% by weight incorporated into upper 0.15 meter	---
SOILGARD (elastomeric polymer)	Alco Chemical Corp.	Mix with soil	---
Soil Seal (formulation of copolymers)	Soil Seal Corp.	Mix with soil	---
Sulphonates and Lignosulphonates (compaction aids)	---	6% by weight into upper 0.15 meter	---
TACSS or Misui Stopper (class of polyurethane monomers)	---	Surface applied, 100% coverage	---
Technical Protein Colloid 1-V	Swift & Co.	---	---
Technical Protein Colloid 5-V	Swift & Co.	---	---
Technical Protein Colloid 2236	Swift & Co.	---	---
Technical Protein Colloid 2260	Swift & Co.	---	---
Thermal Stabilization	---	---	Ingles & Metcalf
Volclay	American Colloid Inc.	---	---
WICALOID Latex 7035(AD) (carboxylated styrene-butadiene latex)	Wica Chemicals	---	---

APPENDIX B
IMPACT ASSESSMENT

B.1 INTRODUCTION

This appendix presents the steps to be followed to obtain information from Sections 1 through 3 of each chapter to derive area recovery index numbers. These numbers are then used to identify preferred and unacceptable cleanup treatments. The ranking of the impacts of these cleanup treatments is also discussed.

B.2 DERIVATION OF RECOVERY INDEX FROM SUCCESSIONAL SERE

The following steps describe the methods to be used to obtain the information shown on Tables B-1 and B-2 under column 3, titled "Duration of Succession Stage:"

1. List the stages in the sere for the land type, starting from bare ground and continuing through climax (herbs, shrubs, softwoods, and hardwoods) in a loosely tabular format. Indicate the major stages of co-dominance and assume secondary succession.
2. List the physiognomy stages appropriate to the land type (canopy closure, subclimax, climax) opposite their successional equivalents, where both occur.
3. List in a third column the range in years that successional stages and physiognomy stages last in the sere. The years do not need to be continuous between two ranges, e.g., 0-3 followed by 9-13 years.

Inflection points on the curves of Figure B-1 prepared for the species diversity, cover, and primary productivity changes over the years from t_0 to 100 or 200 years for 0-1 Natural Rehabilitation (Section 5) are examples. The Recovery Scenario of Section 5 applies a similar assessment routine to derive descriptions of recovery at specific points in time: 1 year, 5 years, 50 years, and 100 years after cleanup. For example;

1. Select a median year for each time range of column 3 (Duration of Succession Stage). Where no median is available in the literature

Table B-1. Hypothetical forest sere.

Succession	Physiognomy Stage	Duration of Succession Stage	Median Year of Succession	Median Years to Climax	Relative Recovery Index
Mixed herbs (grasses & forbs)	Pioneer invasion	0-10	3	200	5
Grasses	Cover closure	10-20	15	185	4
Shrubs	Canopy closure	20-30	25	175	3
Softwoods	Crown cover	30-100	70	130	2
Co-dominants (Softwoods & Hardwoods)	Subclimax	100-150	120	80	1
Hardwoods	Climax	150-300	200	0	0

Table B-2. Hypothetical grassland sere.

Succession	Physiognomy Stage	Duration of Succession Stage	Median Year of Succession	Median Years to Climax	Relative Recovery Index
Herbaceous	Pioneer herbs	0-2	1	200	4
Annual Grasses	Covered surface	9-13	12	190	3
Co-dominance	Transition	18-20	20	180	2
Bunch grasses	Subclimax	25-75	60	40	1
Tall grass Prairie	Climax	100- ?	200	0	0

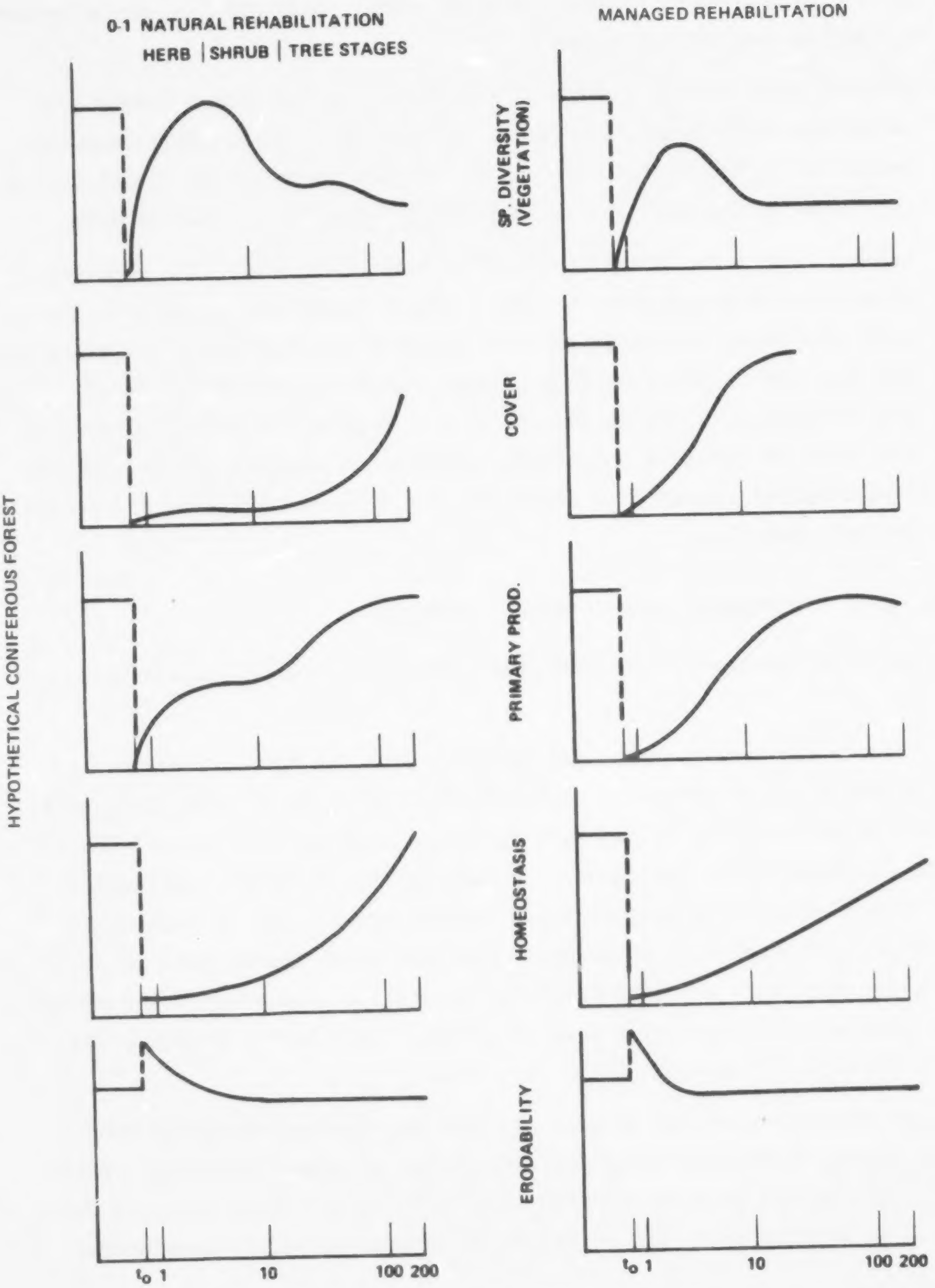

Figure B-1. Example of times for recovery from cleanup in coniferous forest by natural and managed rehabilitation.

assume the years are on a logarithmic scale and the median is the log of the mean (skewed towards the high side). List the medians in column 4 (Median Year of Succession).

2. Subtract each of the medians in column 4 from the climax median and enter the differences in column 5 (Median Years to Climax), rounding years >50 to the next decade either forward or backward. Label column 5 as "Years to Climax," observing that the entry for climax is zero.
3. Label column 6 as "Relative Recovery Index" and enter zero opposite climax in the physiognomy column. Select significant stages in the sere (for which quantitative data in years are available) as guideposts for the Index. Starting from climax, which is zero in the Index, assign numbers to the guideposts so the sequence increases upwards to the start of the sere. Hardening surface becomes N+1 and N+2 becomes "Intervention required to enter sere." For practical use, N+2 should be less than 10.

B.3 RANKING OF DISTURBANCE FROM CLEANUP TREATMENTS

The following paragraphs describe the ranking of cleanup impacts upon 0.01 km^2.

To evaluate the time required for recovery from the cleanup, define the physical disturbance caused upon 0.01 km^2 of the land type by performing each one of the treatments given in the working matrix, between 0-1 Natural Rehabilitation and 7-0 Adding Soil Amendments. Enumerate the potential disbenefits that will impact natural revegetation and specify which kinds of vegetation will be helped and which will be harmed. Consider erosiveness, soil moisture relationships, fertility and soil tilth reconstitution requirements for revegetation to reenter into succession towards climax. This is the material for Section 4, Effects of Cleanup (damage assessment).

Discuss the retrogressive effects the physical disruption causes upon climax conditions in the land type for each of the cleanup procedures. Estimate which part of the sere revegetation will start with, which parts of succession can be skipped over, and which cannot be omitted in the physiognomy progression.

Rank the impacts caused by each cleanup on specific parameters important in the ecosystem and compile a summary of the rankings as in Table B-3. Define the assumptions made during the ranking and record them (see Table B-4, column 7) for the final tabulation in Section 6, Quantitative Assessment. Assemble the known data, on years to return to climax after specific impacts, from Sections 1 through 3 and enter the years in Table B-4, Years Estimated to Reach Climax. Estimate the missing years for the 0.01 km^2 column of Table B-4 by using the ranked impacts in Table B-3.

Next consider the effect that increasing the area cleaned up will have upon the years estimated to pass before the sites reenter climax. For each cleanup treatment extrapolate, the recovery years following retrogression from climax to areas larger than 0.01 km^2 and evaluate the impacts at 0.10, 1.0, 10.0 and 100 km. Discuss those cleanups as a unit that reattain climax by passing through similar numbers of stages of succession. This discussion forms the interpretive backbone of Section 6, Quantitative Assessment. Fill in the remaining four columns of Table B-4, Years Estimated to Reach Climax.

Pick a sequence of points in time to discuss that extends from the first year after cleanup until climax has been reattained. Compare that scenario to columns 1 and 2 of Tables B-1 and B-2, at frequent intervals in succession, and group those treatments together that pass through the same physiognomy stages at the same time. These assessments, when written up, constitute the text of Section 5, "Recovery After Cleanup." The text should also include comparisons of the times like groups require to attain climax and should identify irreversible impacts.

B.4 RECOVERY INDEX NUMBER ASSIGNMENT

Use the median year of succession for the cleanup treatment (Table B-4) as the entry into the treatment-km^2 matrix, basing the median on the stage of succession or stage of physiognomy generated under the heading "Derivation of Recovery Index from Successional Sere." Median years are required for 0.01, 0.1, 1.0, and 10.0 km^2 areas for each treatment in the matrix (Section 6). Those treatments that were deleted should be indicated by an asterisk. Those which require man's intervention before they enter into succession are to be given # symbols. An NA should be used in the matrix for treatments that should not be used in the land type, otherwise defined as irreversible impacts. Transfer the "Assumptions" from column 7, Table B-4 to column 7, Table B-6.

Table B-3. Evaluation of the effects of cleanup procedures.

Environmental Parameter	Ranked Treatment Effect (least effect ⟶)
Plant Succession	4-1 >>> 2-6 > 2-3 > 2-2 > 2-1 > 1-4 > 1-8 > 1-7 > 1-3 > 1-6 > 1-2 = 1-5 > 5-0 > 3-0
Wildlife (small animals)	4-1 >>> 2-6 > 2-3 > 1-8 > 2-1 ≥ 1-7 ≥ 1-4 = 2-2 > 1-5 > 1-3 > 1-6 > 1-2 > 5-0 > 3-0
Wildlife (large animals)	4-1 > 3-0 > 2-6 = 2-3 >> 1-8 > 2-1 > 2-2 ≥ 1-7 ≥ 1-4 > 1-3 = 1-5 > 1-6 > 1-2 > 5-0
Water Runoff	4-1 >>> 2-6 > 2-3 > 2-2 > 2-1 = 1-4 = 1-7 ≥ 1-8 ≥ 1-5 > 1-3 ≥ 1-6 ≥ 1-2 > 3-0 > 5-0
Soil Erosion*	2-2 > 1-4 = 2-1 > 1-7 ≥ 1-8 > 1-5 > 1-6 > 1-3 > 1-2 >> 5-0 > 3-0 >> 2-8 > 2-3 >>> 4-1
Microclimate	4-1 > 2-6 = 2-3 = 1-2 = 1-3 = 1-4 = 1-5 = 1-6 = 1-7 = 1-8 = 2-1 = 2-2 >>> 3-0 = 5-0

*The effects are assumed to be limited to erosion on site, off-site sedimentation is not considered.

Key to effects ranking:	1-2	Clear Cutting	2-1	Soil Removal (<15 cm)
	1-3	Stumping and Grubbing	2-2	Soil Removal (>15 cm)
	1-4	Scraping and Grading	2-3,4,5	Soil Removal, Mechanically Stabilize by Compaction
	1-5	Shallow Plowing		
	1-6	Deep Plowing	2-6,7,8	Soil Removal, Chemically Stabilize
	1-7	Soil Cover (<25 cm)	3-1,2,3	Animal Barriers (including people)
	1-8	Soil Cover (>25 cm)	4-1,2	Hard Surface Stabilization (asphalt, concrete)
			5-0	Sewage Sludge Application

Table B-4. Years estimated for hypothetical ecosystem to reach climax after the indicated cleanup.

Action Evaluated	Area Disturbed (km^2)					Assumptions
	0.01	0.1	1.0	10.0	100.0	(Precleanup state is climax)
0-1 Natural Rehabilitation	150	150	160	170	200	No seed reserve, average seed bed
1-1 Chemical Stabilization	90	90	100	110	>200	Seed reserve, average seed bed
1-2 Remove Vegetation by Clear Cutting	60	60	60	70	90	Seed reserve, good seed bed
1-3 Remove Stumps and Grub Roots	70	70	80	90	100	Seed reserve, good seed bed
1-4 Surface Scraping and Grading (<5 cm)	80	80	90	100	150	Some seed, poor seed bed, erosion
1-5 Shallow Plowing (<10 cm)	60	60	60	70	90	Seed reserve, good seed bed
1-6 Deep Plowing (10 to 40 cm)	70	70	70	80	100	Some seed, good seed bed
1-7 Soil Cover (<25 cm)	150	150	170	180	>200	No seed reserve, average seed bed, erosion
1-8 Soil Burial (25 to 100 cm)	150	150	170	180	>200	No seed reserve, average seed bed, erosion
2-1 Remove Plow Layer Soil (10 cm)	160	160	180	>200	>200	No seed reserve, poor seed bed, erosion
2-2 Remove Shallow Root Zone Soil (<40 cm)	180	190	200	200	>200	
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	200	200	200	200	200	No seed reserve, very poor compacted seed bed
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	200	200	200	200	200	No seed reserve, very poor compacted seed bed
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	200	200	200	200	200	No seed reserve, very poor compacted seed bed
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	200	200	200	200	200	No seed reserve, very poor compacted seed bed
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	200	200	200	200	200	No seed reserve, very poor compacted seed bed
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	200	200	200	200	200	No seed reserve, very poor compacted seed bed
3-1 Barriers to Exclude People	0	0	0	0	0	Applied to climate
3-2 Barriers to Exclude Large Animals	0	0	0	0	0	No significant effects on climax*
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	0	No significant effects on climax
4-1 Asphalt Hard-Surface Stabilization	>200	>200	>200	>200	>200	At least 50 years required for concrete breakup
4-2 Concrete Hard-Surface Stabilization	>200	>200	>200	>200	>200	
5-0 Sewage Sludge Application	0	0	0	0	0	No significant effects on climax*
6-1 Washing (<3 mm)	0	0	0	0	0	No significant effects on climax*
6-2 Flooding (3 to 30 cm)	0	0	0	0	0	No significant effects on climax*
7-0 Soil Amendments Added	0	0	0	0	0	No significant effects on climax*

*The sampling (variability between sites) error greatly exceeds the instrumental (treatment) error.

Go to Section 7 and select the least damaging treatments and discuss their advantages over other treatments as part of the Conclusions Section (Section 7). Perform the same analysis for treatments that are not usable on the land type, rated # or NA in Tables B-5 and B-6.

Once the recovery times and the area effects are evaluated complete the Recovery Index and Guide Numbers, columns 6 and 7 in Table B-5. Cleanup that leaves the site at climax is rated as zero impact even though it may be some time before it regains productivity, for example mowing bunchgrass. The Index Numbers "count" the stages in a sere. The largest one represents the greatest site retrogression and the longest recovery time to regain climax; its Guide Number is N. Cleanup recovery that will progress through succession but delays in starting recovery is more severe than those which begin succession immediately. Nevertheless, they are of the same order and kind of recovery as those with a smaller Recovery Index, and the Guide Number is increased one to account for the greater time for recovery, from N to N+1. An example of an N+1 Guide Number is that of breakup of asphalt hard surface that delays succession 20 years in the hypothetical coniferous forest of Table B-5.

In some ecosystems, cleanup can provide changes which allow secondary impacts severe enough to prevent a succession occurring that leads to the pre-cleanup climax. One example is removal of the plow layer from conifers on a shallow soil on a steep hillside, taking the accumulated organic matter and surface horizon mineral soil. Subsequent erosion over time can eliminate the contaminated, cleaned-up site by replacing it with a gully that continues to the barren bedrock. The original forested site no longer exists. In this case, the timely intervention by site renovators could return the site of cleanup into conditions that bring back the prior sere. These cleanup impacts are defined as the "Conditional Stage" and are another one of the pre-succession stages. They are given a Recovery Index that is non-numerical (the symbol used in Table B-5 is #); the analogous Guide Number is N+2, which should be less than 10 for convenience.

The final Guide Number is that assigned to cleanup impacts which produce "Irreversible" impacts and in Table B-5 the acronym is NA. This concludes the mechanism for generating Index and Guide Numbers to represent the impacts caused by contamination cleanup.

Table B-5. Hypothetical coniferous sere as represented by the development of a Spruce-hemlock forest on mineral soil exposed by glacial retreat.*

Succession Stage	Physiognomy Stage	Duration of Succession Stage (years)	Median Year of Succession	Years to Climax	Recovery Index	Guide Numbers
deciduous shrubs	pioneer invasion	0-7	2.5	200	6	N
mixed shrubs	cover closure	7-10	8.4	190	5	
Brush thicket	crown cover	10-60	35.0	165	4	
deciduous trees	crown cover	60-90	74.0	125	3	
intolerant conifers	sub climax	90-170	130.0	70	2	
mixed conifers	climax	130-200	170.0	30	1	
muskeg	retrogression	>200	200	0	0	0
delayed	(asphalt breakup)	10-25	220	>200	7	N+1
conditional	site retrogression excessive	until renovated**	—	—	#	N+2
irreversible retrogression	site retrogression excessive	permanent	—	—	NA	N+3

* After Lawrence[1]

**Requires one or more site renovation treatments: terrace, drain, reseed, transplants, fertilizer, irrigation, mulching (human intervention).

Table B-6. Recovery indexes for cleanup of hypothetical coniferous forest.

Action Evaluated	Area Disturbed (km^2)					Assumptions
	0.01	0.1	1.0	10.0	100.0	(Precleanup state is climax)
0-1 Natural Rehabilitation	4	4	5	5	6	
1-1 Chemical Stabilization	2	2	3	3	6	
1-2 Remove Vegetation by Clear Cutting	2	2	2	2	2	
1-3 Remove Stumps and Grub Roots	2	2	2	2	2	
1-4 Surface Scraping and Grading (<5 cm)	2	2	2	3	4	
1-5 Shallow Plowing (<10 cm)	2	2	2	2	2	
1-6 Deep Plowing (10 to 40 cm)	2	2	2	2	3	
1-7 Soil Cover (<25 cm)	4	4	4	5	6	
1-8 Soil Burial (25 to 100 cm)	4	4	4	5	6	
2-1 Remove Plow Layer Soil (10 cm)	4	4	4	6	7	
2-2 Remove Shallow Root Zone Soil (<40 cm)	5	5	6	7	7	
2-3 Scrape Surface, Remove (<5 cm), Mechanically Stabilize	7	7	7	7	7	
2-4 Remove Plow Layer (10 cm), Mechanically Stabilize	#	#	#	#	#	
2-5 Remove Shallow Root Zone (<40 cm), Mechanically Stabilize	#	#	#	#	#	
2-6 Scrape Surface, Remove (<5 cm), Chemically Stabilize	4	4	4	5	7	
2-7 Remove Plow Layer (10 cm), Chemically Stabilize	4	4	4	5	7	
2-8 Remove Shallow Root Zone (40 cm), Chemically Stabilize	4	4	4	5	7	
3-1 Barriers to Exclude People	0	0	0	0	0	
3-2 Barriers to Exclude Large Animals	0	0	0	0	0	
3-3 Barriers to Exclude Large and Small Animals	0	0	0	0	0	
4-1 Asphalt Hard-Surface Stabilization	#	#	#	#	#	
4-2 Concrete Hard-Surface Stabilization	#	#	#	#	#	
5-0 Sewage Sludge Application	0	0	0	0	0	
6-1 Washing (<3 mm)	*	*	*	*	*	
6-2 Flooding (3 to 30 cm)	*	*	*	*	*	
7-0 Soil Amendments Added	*	*	*	*	*	

*Outside scope of work.

B.5 APPENDIX B REFERENCE

1. Lawrence, D. B. The Glaciers and Vegetation in Southeastern Alaska. American Scientist, Summer 1958. pp. 89-122.

APPENDIX C

LAND TYPES

Aeolian Mountain Peaks — High mountain terrain above trees and flowering plants, above alpine zones.

Coastal Inter-Tidal Marsh — Low, flat marshlands traversed by interlaced channels amid tidal sloughs and subject to tidal inundation; normally, the only vegetation present is salt-tolerant bushes and grasses.

Coniferous Forest — A plant association predominantly of trees of the order Coniferae, having evergreen leaves shaped like needles or scales; such trees produce softwood lumber. Understory may be highly variable, from humid ferns to semiarid grasses and shrubs.

Deciduous Forest — A plant association predominantly of trees and other woody vegetation which seasonally loses all its leaves.

Desert — An area of land that has an arid, hot to cool climate with vegetation that is sparse and usually shrubby.

Prairie — A tract of level to hilly land that has a dominance of grasses and forbs, has a scarcity of shrubs, and is treeless. The natural plant community consists of various mixtures of tall, mid- and short-growing native species, also known as true prairie, mixed prairie, and shortgrass prairie, respectively.

Salt Marsh — Low area adjacent to the sea that is covered with salt-tolerant vegetation and regularly flooded by the high tide; similar inland areas near saline springs or lakes, though not regularly flooded.

Tundra — The treeless land in arctic and alpine regions; varying from bare area to various types of vegetation consisting of grasses, sedges, forbs, dwarf shrubs, mosses, and lichens.

APPENDIX D

CLEANUP TREATMENTS

Treatment Number	Treatment Name	
1-1	Chemical Stabilization	Erosion prevention through the use of soil additives to promote increases in soil cohesion or shear strength, bulk density, water retention, and/or surface cohesion (see Appendix A).
1-2	Clearcutting	A method of cutting that removes the entire vegetational stand; usually refers to lumbering operations. Synonyms here include mowing.
1-3	Stumping and Grubbing	The operation of removing stumps and roots.
1-4	Surface Scraping and Grading	Removal of the upper soil layers to 5 cm by means of bulldozers, road graders, or other heavy or medium equipment with controlled cutting.
1-5 1-6	Plowing	Employment of a device to cut, lift, break up, and turn over the soil, usually leaving parallel furrows on the surface. Depth ranges are: Shallow (<10 cm) and Deep (10 — 40 cm).
1-7 1-8	Soil Cover	Soil collected from uncontaminated borrow pits, surface areas, road excavations; generally expected to be a poorer medium for plant growth than the soil covered up.
2-1	Removal of Plow Layer Soil	"Plow layer soil" defined here as from surface to depth of about 10 centimeters. Removal can be by hand shoveling, bulldozers, scrapers, front-end loaders.
2-2	Removal of Shallow Root Zone Soil	"Shallow root zone" defined as that part of the soil, up to a depth of 40 cm, that is penetrated or can be penetrated by plant roots.
2-3 2-4 2-5	Surface Soil Removal with Mechanical Stabilization	Physical removal of contaminated surface and soil from the affected area with depth-controlled equipment, dozers, front-end loaders, or scrapers. The exposed surface remaining is mechanically compacted to a maximum density by heavy equipment or is resurfaced with impervious materials such as soil-cement or NaCl. The resultant effect is to remove the contaminant and to seal the exposed surface against water infiltration. 2-3 The cut removes less than 5 cm of material. 2-4 Up to 10 cm of material may be removed.

		2-5 Removes the shallow root-zone and may extend to 40 cm. The deepest soil removal may cause temporary impoundment of surface waters.
2-6 2-7 2-8	Surface Soil Removal with Chemical Stabilization	The physical operations for these treatment procedures are similar to those discussed for 2-3 to 2-5. The basic differences between the two treatment types are: a. the method of subsurface stabilization b. the size of the treated area. Chemical subsurface stabilization is the application of one of the chemical forms of stabilizers as defined in "Appendix A, Stabilizers" to create change in the physical soil structure. Most chemical stabilizers are restricted to areas in size where the surface soils were removed by hand methods or with small tractor end-loader equipment (from 0.01 km^2 to 0.1 km^2). The usual application of the selected chemical stabilizer is by hand methods. This foregoing description must not be construed to preclude the use of chemical stabilization on larger areas where heavy equipment can be used for the chemical application. However, the treatment is generally restricted to smaller areas or to urban situations.
3-1 3-2 3-3	Barrier	A vertical impediment such as a wall or fence which serves to prevent horizontal animal movements. A reinforced heavy high barrier for large animals (bison, moose, elk) and a buried edge fine mesh barrier (including sheet metal flashing) to impound small animals (pocket mouse, moles, grass vole, but excluding bats). Horizontal barriers (screens or sheets) may also be employed to prevent vertical animal movements.
4-0 4-1 4-2	Mechanical Stabilization (asphalt) (concrete)	Erosion prevention through compaction of the surface soil through tamping, rolling, vibration, electrostatic methods, plastic sheeting, and other non-chemical means. Hard-surface stabilization (paving) is included here.
5-0	Sewage Sludge	Settled sewage solids combined with varying amounts of water and dissolved materials that are removed from sewage by screening, sedimentation, chemical precipitation, or bacterial digestion. Application may serve to increase soil permeability, increase soil fertility, and increase soil water retention, thus reducing soil erosion and contaminant mobility.

6-1	Washing	A system to spray water under high pressure over streets, buildings and impermeable surfaces to suspend and remove contamination in a volume of water equivalent to 3 mm or less over the washed surface.
6-2	Flooding	Inundation of a surface by water in an effort to wash a contaminant downslope or into deeper soil regions, using 3 to 30 cm of water.
7-0	Soil Amendment	Any material, such as lime, gypsum, sawdust, or synthetic conditioner, that is worked into the soil to make it more amenable to plant growth. Plant growth is stimulated to act as a surface cover and thus as an erosion preventative; some amendments may also serve to prevent contaminant uptake by plants or to promote contaminant uptake by plants, in which case the plants could be removed for storage as contaminated wastes, having incorporated the contaminant in their tissues.

APPENDIX E

GLOSSARY

Aeolian Soil Material — Soil material accumulated through wind action.

Adsorption — The molecular attraction of a substance to the surface of a solid or liquid.

Afforestation — The artificial establishment of forest crops by planting or sowing on land that has not previously, or recently, grown trees.

Agricultural Land — Land in farms regularly used for agricultural production.

A Horizon — See Soil Horizon.

Algae — Simple plans, many microscopic, containing chlorophyll; forming the base of the food chain in aquatic environments.

Alluvial — Pertaining to material that is transported and deposited by running water.

Alpine — That portion of mountains above tree growth or organisms living there.

Animal Unit — A measurement of livestock numbers based on the equivalent of a mature cow (approximately 1,000 pounds live weight).

Annual Plant — A plant that completes its life cycle and dies in 1 year or less.

Ap — The surface layer of a soil disturbed by cultivation or pasturing.

Arborescent — Resembling a tree in properties, growth, structure, or appearance.

Arid — Regions or climates that lack sufficient moisture for crop production without irrigation.

Aspect (forestry) — The direction that a slope faces.

Autogenic — Orginating within.

Autotroph — An organism that manufactures its own food, such as a plant.

Benthos — The plant and animal life whose habitat is the bottom of a sea, lake, or river.

Berm — A shelf or flat area that breaks the continuity of a slope.

B Horizon — See Soil Horizon.

Biocoenosis — The plants and animals comprising a community.

Biomass — The total amount of living material in a particular habitat or area.

Biome — A unit of plant and animal communities having similarities in form and environmental conditions.

Biota — The flora and fauna of a region.

Blowout — (1) An excavation in areas of loose soil produced by wind; (2) a rupture of soil surface attributable to hydraulic pressure.

Bole — The trunk of a tree.

Boreal — Of, relating to, or located in northern regions.

Brunizem (Prairie) Soils — The group of soils developed under tall grasses in a temperature, relatively humid climate.

Buffer Strips — Strips of erosion-resisting vegetation between cultivated strips or fields.

Canopy — The cover of leaves and branches formed by the tops or crowns of plants.

Catch Crop — 1) A crop produced incidental to the main crop, usually occupying the land for a short period; 2) A crop grown to replace a main crop which has failed.

Check Dam — Small dam constructed in a small watercourse to decrease the streamflow velocity, minimize channel scour, and promote deposition of sediment.

Chiseling — Breaking or loosening the soil with a chisel cultivator or chisel plow.

C Horizon — See Soil Horizon.

Ciliated — Provided with a minute hairlike process of many cells that is capable of lashing movement.

Clearcutting — A cutting method that removes the entire timber stand.

Climate — The total of all atmospheric or meteorological influences, principally temperature, moisture, wind, pressure, and evaporation.

Climax — The terminal stabilized system of an ecological succession.

Clone — A group of organisms derived by asexual reproduction from a single parent.

Coarse Texture — The soil texture exhibited by sands.

Co-dominant Trees — Trees with crowns forming the general level of the forest canopy and receiving full light from above but comparatively little from the sides.

Colluvial — Material that has moved downhill and has accumulated on lower slopes and/or at the bottom of the hill; material of avalanches.

Community — An aggregation of organisms within a specified area.

Compaction — The process by which soil grains are compressed, thereby increasing the weight of solid material per cubic foot.

Conifer — A softwood tree belonging to the order *Coniferae* with cones and evergreen leaves of needle shape or "scalelike."

Contour Ditch — Irrigation ditch laid out approximately on the contour.

Contour Farming — Plowing, planting, cultivating, and harvesting on the contour.

Coppice — A growth of small trees originating mainly from sprouts or root suckers rather than from seed.

Copse — Coppice.

Cover, Percent — The area covered by plants and mulch expressed as a percent of total area.

Cropland — Land used primarily for the production of cultivated crops.

Crown (forestry) — The upper part of a tree, including the branches and foliage.

Crown Class — All trees in a stand with tops or crown occupying a similar position in the canopy. Crown classes usually distinguished are:

Dominant — Trees with crowns extending above the general level of the forest canopy.

Co-dominant — Trees with crowns forming the general upper level of the forest canopy.

Crown Cover — The canopy formed by the crowns of all the trees in a forest.

Cutting Cycle — The planned interval between major cutting operations in a managed woodland tract.

Deciduous Plant — A plant that sheds all its leaves every year at a certain season.

Deflocculate — To separate the individual particles of compound aggregates by chemical and/or physical means.

Delta — An alluvial deposit formed where a stream or river drops its sediment load on entering a body of more quiet water.

Dendritic — Tree-like.

Detritus — Matter worn from rocks by mechanical means; generally, alluvial deposits.

Diatom — Algae with silicified skeletons.

Dominant (ecology) — Species which by their activity, behavior, or number have considerable influence or control upon the conditions of existence of associated species.

Duff — The organic layer on top of mineral soil.

Ecology — The study of interrelationships of organisms to one another and to their environment.

Ecosystem — A community, including all the component organisms, together with the environment, forming an interacting system.

Ecotone — A transition strip of vegetation between two communities, having characteristics of both kinds of neighboring vegetation as well as characteristics of its own.

Environmental Impact Statement — A document detailing the environmental impact of a proposed action that may significantly affect the quality of the environment.

Erosion — The wearing away of land surface by running water, wind, ice, or other geological agents.

rill erosion — a process in which numerous small channels only several inches deep are formed.

sheet erosion — the removal of a fairly uniform layer of soil from the land surface by runoff water.

splash erosion — the spattering of small soil particles caused by the impact of raindrops on wet soils.

Evergreen — Perennial plants that are never entirely without green foliage.

Fallow — Allowing cropland to lie idle, either tilled or untilled, during the whole or greater portion of the growing season.

Farm Forestry — The practice of forestry on farm or ranch lands generally integrated with other farm or ranch operations.

Fertilizer — Any organic or inorganic material that is added to a soil to supply elements essential to plant growth.

Fibrous Root System — Having a large number of small, finely divided, widely spreading roots but no large individual roots.

Field Planting (forestry) — The establishment of woody plants on land essentially free of trees.

Forb — An herbaceous plant which is not a grass, sedge, or rush.

Fragipan — A natural subsurface horizon, low in organic matter, with high bulk density; seemingly cemented when dry but showing a brittleness when moist.

Frost Heave — The raising of a surface due to the accumulation of ice in the underlying soil.

Gabion — A wire mesh cage filled with rock and used as a protecting apron against erosion.

Gley (soil) — pale gray to bluish white horizon high in ferrous compounds and other oxygen deficient decomposition products.

Grass — A member of the botanical family *Gramineae*,characterized by bladelike leaves arranged on the stem in two ranks.

Grove — A small group of trees, usually without understory, planted or natural.

Gully Control Plantings — The planting of forage in gullies to establish a vegetative cover adequate to control runoff and erosion.

Habitat — The environment in which the life needs of a plant or animal organism are supplied.

Hardwoods — Trees that have broad leaves, in contrast to the conifers; also wood produced by trees of this group regardless of texture.

Herb — Any flowering plant except those developing persistent woody bases and stems above ground.

Heterotrophic — Pertaining to organisms that are dependent on organic material for food.

Homeostasis — Ecologic inertia of a population, under stress by changing conditions, which restores a prior equilibrium through self-adjustment.

Hydric — Requiring an abundance of moisture.

Hydrophyte — A plant that grows in water or in wet or saturated soils.

Illuvial — A soil layer or horizon in which material carried from an overlying layer has been precipitated from solution or deposited from suspension. The layer of accumulation.

Insolation — Incoming solar radiation.

Interstices — The pore space or voids in soil and rock.

Invader Plant Species — Plant species that were absent in undisturbed portions of the original plant community and will invade under disturbance or continued overuse.

Invasion — The migration and establishment of organisms from one area to another area.

Irreversible — Incapable of correction or of being reversed.

Kame — A conical hill or short irregular ridge or gravel or sand deposited in contact with glacier ice.

Mesic (soil) — formed under a mean annual temperature range of 15° to 22°C (59° to 72°F) at 50 cm depth.

Mesophyte — A plant that grows under intermediate moisture conditions.

Microflora — Bacteria, including actinomycetes, viruses, and fungi.

Mitigation (wildlife) — The reduction or elimination of damages to fish and wildlife resources.

Montane — (1) pertaining to mountain conditions; (2) the lower vegetation belt on mountains.

Moraine — An accumulation of rock debris by the direct action of glacial ice.

Mulch — A natural or artificial layer of plant residue or other materials, such as sand or paper, on the soil surface.

Muskeg — Bog; especially a sphagnum bog of northern North America.

Mycorrhizal — The fungal complex with the roots of a seed plant.

Native Pasture — Land on which the climax plant community is forest, but which is used and managed primarily for the production of native species for forage.

Native Species — A species that is a part of an area's original fauna or flora.

Niche — A habitat that supplies the factors necessary for the existence of an organism or species.

Old-Field — An abandoned agricultural field.

Outwash — The material, cheifly sand or gravel, washed from a glacier by the action of meltwater.

Overburden — The earth, rock, and other materials that lie above a mineral deposit.

Overstory — The portion of the trees in a forest stand forming the upper crown cover.

Phenology — The study of the time of appearance of characteristic periodic events in the life cycles of organisms in nature and how these events are influenced by environmental factors.

Phreatophyte — A plant deriving its water from subsurface sources; commonly used to describe nonbeneficial, water-loving vegetation.

Phytoplankton — Unattached microscopic plants of plankton, subject to movement by wave or current action.

Physiography — A description of nature or natural phenomena in general.

Piping — Removal of soil material through subsurface flow channels developed by seepage water.

Pitting — (1) making shallow pits to retain water from rainfall or snowmelt on rangeland or pasture; (2) small cavities in a surface created by corrosion, cavitation, or subatmospheric pressures.

Plant Succession — The process whereby an area becomes successively occupied by different plant communities of higher ecological order.

Primary Productivity — The rate (grams per day) at which organic matter is stored by photosynthesis and chemosynthesis of producer organisms (autotrophs).

Protozoa — Single-celled animals.

Pyric — Resulting from, induced by, or associated with burning.

Range — (1) Rangeland, and forestlands with understory suitable for grazing; (2) the geographic area occupied by an organism.

Reclamation — The process of reconverting disturbed lands to their former uses or other productive uses.

Rehabilitation — Returning of land to productivity in conformity with prior land use, including a stable ecological state consistent with surrounding aesthetic values.

Relict — A remnant or fragment of a flora that remains from a former period when it was more widely distributed.

Restoration — The process of restoring site conditions as they were before the land disturbance.

Retrogression — Reverse succession under environmental stress.

Savanna — A grassland with scattered trees; often a transitional type between true grassland and forest.

Scarify — To abrade, scratch, or modify the surface.

Scenario — The order of events in time describing interacting forces, environmental influences and organisms.

Scree — (1) Pebble, stone; (2) a heap of stones or rocky debris.

Seedbed — The soil prepared to promote the germination of seed and the growth of seedlings.

Sequum — The generally gradual changes in soil properties in horizontal or vertical directions from the soil body in question.

Seratinous — Late, especially in developing or flowering.

Sigmoidal — A slanted S-shaped curve.

Site (ecology) — (1) an area considered for its ecological factors with reference to capacity to produce vegetation; the combination of biotic, climatic, and soil conditions of an area; (2) an area sufficiently uniform in soil, climate, and natural biotic conditions to produce a particular climax vegetation.

Snow Fence — A fence used in winter to intercept drifting snow, thus protecting roads and other areas from snowdrifts. Also used to impound snow where melting in place adds to soil moisture.

Soil Amendment — Any material, such as lime, gypsum, sawdust, or synthetic conditioner, that is worked into the soil to make it more amenable to plant growth.

Soil Horizon — A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics, such as color, structure, texture, consistence, kinds and numbers of organisms present, degree of acidity or alkalinity, etc. Designations and properties of three major soil horizons are as follows:

A Horizon. Topsoil, the zone of maximum concentration of soil organisms and biotic activity. This is the horizon in which organic debris becomes converted into humus and mixed with mineral matter. It is the zone of eluviation in which precipitation, mixed with acids from decomposing organic matter dissolves and carries further down into the soil the more soluble materials

B Horizon. The lowest true soil, or subsoil. This zone lying below the horizon of maximum leaching is an area of illuviation, or deposition for minerals leached out of the topsoil, and in particular it is a layer in which clays tend to accumulate. In arid regions it will be a layer of accumulation for calcium carbonate, magnesium carbonate, gypsum, or other soluble salts.

C Horizon. A layer of unconsolidated material and rock fragments lying above the unmodified parent rock and below the true soil. It usually contains little material modified by living organisms, although it may be broken, split or cracked by the roots.

Solum — The upper and most weathered part of the soil profile; the A and B horizon.

Spoil — Soil or rock material excavated from a canal, ditch, basin, or similar construction.

Stabilized Grade — The slope of a channel at which neither erosion nor deposition occur.

Stratification — The process or arrangement or composition in strata or layers.

Strip Mining — A process in which rock and top soil strata overlying mineral deposits are scraped away by mechanical shovels. Also known as surface mining.

Substrate — (1) in biology, the base of substance upon which an organism is growing; (2) in chemistry, a substance undergoing oxidation; (3) in hydrology, the bottom material of a waterway.

Succession — The progressive development of vegetation toward its highest ecological expression, the climax; replacement of one plant community by another.

Surface Compaction — Increasing the dry density of surface soil by applying a dynamic load.

Surface Water — All water whose surface is exposed to the atmosphere.

Tacking — The process of binding mulch fibers together by the addition of a sprayed chemical compound.

Taxonomy — (1) the science of classification; (2) classification of animals and plants, such as species, genus, family, and order.

Tilth — The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and impedance to seedling emergency and root penetration.

Topsoil — (1) earthy material used as top-dressing with favorable characteristics for production of desired kinds of vegetation; (2) the surface plow layer of a soil; (3) the dark-colored upper soil that ranges in depth with different kinds of soil; (4) the A horizon, varying widely among different kinds of soil.

Trophic Level — The level in a nutritive series of an ecosystem in which a group or organisms in a certain stage in the food chain secures food in the same general manner. The first or lowest trophic level consists of producers (green plants); the second level of herbivores; the third level of secondary carnivores; and the last level of reducers.

Truncated Soil Profile —Soil profile that has been cut down by accelerated erosion or by mechanical means. The profile may have lost part or all of the A horizon and sometimes the B horizon, leaving only the C horizon.

Undergrowth (forestry) — Seedlings, shoots, and small saplings under an existing stand of trees.

Understory — That portion of the trees in a forest below the upper crown cover, also called underwood.

Urban Land — Areas so altered or obstructed by urban works or structures that identification of soils is not feasible. A miscellaneous land type; towns of over 2,500 are defined as urban by the U.S. Bureau of Census.

Vegetation — Plants in general or the sum total of plant life in an area.

Vertical Stratification — The process of arrangement or composition in strata or layers vertically, as in understory shrubs and overstory tree canopy.

Wildlife — Undomesticated vertebrate animals, except fish, considered collectively.

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